CO-RELATION OF VARIABLES INVOLVED IN THE OCCURRENCE OF CRANE ACCIDENTS IN THE U.S. THROUGH LOGIT MODELING

A Thesis

by

AMRIT ANOOP SINGH BAINS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2010

Major Subject: Construction Management

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Approved by:

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	Ho-Yeong Kang
Committee Member,	Mark Clayton
Head of Department,	Joe Horlen

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ABSTRACT

Co-relation of Variables Involved in the Occurrence of Crane Accidents in the U.S. through Logit Modeling. (August 2010)

Amrit Anoop Singh Bains, B.Arch., Panjab University, India

Co-Chairs of Advisory Committee: Dr. Boong Yeol Ryoo
Dr. Ho-Yeong Kang

One of the primary reasons of the escalating rates of injuries and fatalities in the construction industry is the ever so complex, dynamic and continually changing nature of construction work. Use of cranes has become imperative to overcome technical challenges, which has lead to escalation of danger on a construction site. Data from OSHA show that crane accidents have increased rapidly from 2000 to 2004. By analyzing the characteristics of all the crane accident inspections, we can better understand the significance of the many variables involved in a crane accident.

For this research, data were collected from the U.S. Department of Labor website via the OSHA database. The data encompass crane accident inspections for all the states. The data were divided into categories with respect to accident types, construction operations, degree of accident, fault, contributing factors, crane types, victim's occupation, organs affected and load. Descriptive analysis was performed to compliment the previous studies, the only difference being that both fatal and non-fatal accidents have been considered.

Multinomial regression has been applied to derive probability models and correlation between different accident types and the factors involved for each crane accident type. A log likelihood test as well as chi-square test was performed to validate the models. The results show that electrocution, crane tip over and crushed during assembly/disassembly have more probability of occurrence than other accident types. Load is not a significant factor for the crane accidents, and manual fault is more probable a cause for crane accident than is technical fault. Construction operations identified in the research were found to be significant for all the crane accident types. Mobile crawler crane, mobile truck crane and tower crane were found to be more susceptible. These probability models are limited as far as the inculcation of unforeseen variables in construction accidents are concerned. In fact, these models utilize the past to portray the future, and therefore significant change in the variables involved is required to be added to attain correct and expedient results.

DEDICATION

This thesis is dedicated to my wonderful parents, Daljeet Kaur Bains and Balwinder Singh Bains, who have raised me to be the person I am today. You have been with me every step of the way, through good times and bad. Thank you for all the unconditional love, guidance, and support that you have always given me, helping me to succeed, and instilling in me the confidence that I am capable of doing anything I put my mind to. Thank you for everything. I love you!

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Special thanks go to my special friends Rahul Goel and Mandeep Singh Pannu, their technical knowledge and guidance were absolute quintessence for the completion of this thesis. They truly are friends indeed. I am highly grateful to Dr. Derya Akelman for imparting such a useful knowledge of statistics to me. I would also like to take this opportunity to thank all those guys who have made my experience at Texas A&M University a great one.

There are other debts more of a personal nature I must acknowledge. Throughout the writing and learning process of this thesis, spiritual music and holy recitations by Bhai Harjinder Singh (Srinagar Wale) and Nusrat Fateh Ali Khan have been a constant source of strength to focus and concentrate resulting in work produced to the best of my ability.

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NOMENCLATURE

Term	Definition
OSHA	Occupational Safety and Health Administration (United States of America)
ANSI	American National Standards Institute
CIRPC	Construction Industry Research and Policy Center
IMIS	Integrated Management Information Systems
NIOSH	National Institute for Occupational Safety and Health
CRS	Congressional Research Service
ASCE	American Society of Civil Engineers
CPWR	Center for Construction Research and Training
NOAA	National Oceanic and Atmospheric Administration
OLS	Ordinary Least Squares
SPSS	Statistical Package for the Social Sciences
MNL	Multinomial Logit
CSHO	Compliance Safety Health Officers
SIC	Standard Industry Classification
df	Degrees of Freedom
Sig.	p-value
LL	Log Likelihood

1. INTRODUCTION

1.1. Background

Crane Safety is a major concern because of the economic and social costs of the crane accidents (Hunt, 2008). Cranes, which come in numerous configurations and are a critical component of most construction work, contribute to as many as one-third of all construction and maintenance fatalities and injuries resulting in permanent disability (MacCollum, 1993). Recent NIOSH investigations suggest that safety managers may not fully recognize the hazards associated with operating or working mobile cranes. (MacCollum, 1993) has made best estimates that crane hazards are the source of about 25 ± 33% of causalities in construction and maintenance activities. In fact OSHA's crane and derrick standard has been virtually unchanged since its promulgation in 1971 (Levine, 2008).

With the advent of technology, materials and sophistication of design, construction of buildings have been escalating vertically ever since. Cranes are the favorite tools for North American Contractors and indeed the nexus for United States Construction Industry (Bishop, 2000). Without the cranes, constructing skyscrapers would have been almost impossible and in fact they are the centerpiece of most of the building projects even if the construction is not high-rise.

This thesis follows the style of *Transportation Research Part A.*

Henceforth sophistication and use of cranes in the industry has increased manifold over the years and so has the complexity associated with it, resulting in many fatal accidents (Rivara & Alexander, 1994). Current scenario of safety in construction follows zero tolerance rules, and hence the regulations (OSHA, Crane Accidents, 2010) are becoming stringent to stop any mishaps on construction sites. These regulations define both the technical and manual guidelines (Veazie, Landen, Bender, & Amadus, 1994) which should be taken care off; still accidents do happen. Hence, the need arises to address safety issues concerning cranes and their operation in an environment where these resources are being utilized in a bountiful manner. Most of the research that has been performed on crane accidents has focused on the figurative analysis of U.S. department of Labor Statistics (Neitzel & Seixas, 2001). A great deal of research done is limited to mere numbers and then recommendations based on that taxonomy (Shepherd, Kahler, & Cross, 2000).

In such a scenario, it becomes important to use alternative methods of research which can prove beneficial in a pragmatic manner by providing concrete numbers and not just overviews. The aim of this research is to statistically analyze the crane accidents based on the crane accidents database of Occupational Safety and Health Administration (OSHA) from years 2000 to 2006 and find significant factors using Logit modeling, which will help in increasing the safety factors for the variables which were significant (Suruda, Egger, Liu, & Liu, 1997) that are involved in a crane failure. Logit Modeling has been a powerful tool for predicting financial, biological and even environmental factors. In fact as stated by Menard, Logit modeling is a statistical technique that spans the “hard” and “soft” science in adaptability and usefulness (Menard, 2009).

1.2. Problem Statement

The construction industry unfortunately continues to remain the leader in as far as accidents and fatalities are concerned. (Suruda, Liu, & Egger, 1997). MacCollum, a recognized authority on crane hazards, has estimated that cranes are involved in 25 to 33% of fatal injuries in construction operations.

The Occupational Safety and Health Administration (OSHA) has had the long-standing mandate to promulgate standards (OSHA, Crane Accidents, 2010) to enforce them. According to the Bureau of Labor Statistics (2007), the United States construction Industry has the highest rate of injury of any major industry. The limitation of selecting accident control practices as other industries and coming up with similar results is due to following reasons.

First, organizational work involves either operations or projects. Operations are ongoing and repetitive, where as many construction projects are unique and temporary (PMI, 2000). Secondly, in construction projects the environment is often uncontrolled (Lee, Shin, Park, & Ryu, 2009) or a construction project has a lot of different variables/parameters from other construction project that may be similar. Unforeseen condition such as weather condition can also impact the output of the project and related safety concerns (Lee, Shin, Park, & Ryu, 2009).

These factors imply that it is highly improbable to make regulations that are universally applicable, but it is probable to derive those variables (Suruda, Egger, Liu, & Liu, 1997) that do not allow the regulations to be indelible.

But none of these studies have examined the parameters in a way that provides a concrete mathematical solution in predicting the accidents and thus preventing them. It is always beneficial to know the previous statistics of accidents but until and unless they are used for future benefits they are unfortunately not worth it.

Although it is a mandate for Occupational Safety and Health Administration (OSHA) to collect injury and illness information (OSHA, Homepage, 2010), but the data is not released annually. Hence, it becomes extremely difficult to analyze the latest trends in crane accidents and the research done is always far and between.

Given the various types of accidents and the different variables which could have possible relation to them, there is a need to derive a qualitative as well as quantitative relation between the two. This relation between the different accidents and the variables can provide guidance to the contractors/safety managers to control those variables in order to prevent the future occurrence of the accidents on site.

1.3. Research Objective

Where efforts have addressed accident-injury severity, the approach has generally been to identify taxonomic analysis of fatalities (Sale, 1998). The ability to understand and address the accident injury-severity potential in a multivariate context (understanding how multiple factors affect accident occurrence distributions) is a priority as far as crane safety is concerned. Also, every crane accident report deals with only fatalities, but there has not been any analysis of non-fatalities involved in crane accidents (Sale, 1998).

Research will provide OSHA managers with a new insight to inspect the accident, i.e. identifying the variables which can certainly provide concrete mathematical solution to accidents. The results from the Logit model will also determine the factors among all the different variables which are significantly affecting the occurrence of an accident type. In practice these results will provide the different construction authorities the efficient ways to reduce certain type of accidents. For example, if the model determines that the occurrence of accident type- slip over is significantly dependent on mobile crawler crane than the most cost- and time-efficient way of reducing the slip over accidents will be to focus more safety factor in to mobile crawler cranes and not all the cranes.

The objective of this research is find a significant factors that are involved in a crane accident. Specifically, this research will consider the latest set of data available, which provides an insight to the latest type of accidents and their causes. Time constraint plays an important role in analyzing the accidents because of ever changing methods and technologies. Data from 2000 to 2006 has been selected because it is the latest set of crane accident investigations that been released by OSHA and no data for time frame since then has been published. Each crash report has been analyzed individually to determine the variables and type of crane accidents. These probability models have further scope of being programmed into computer software giving an instant probability of accident.

1.4. Research Approach

The approach for the research will follow the following four steps-:

- ✓ Analyze the data of crane accidents provided by O.S.H.A(Occupational safety and Health Administration to determine the variables involved(Table 1&2)
- ✓ Analyze the significant variables involved in crane accidents. (To check are there any redundant variables, which have no impact on the probability of accident occurrence)
- ✓ Derive probabilistic model on the occurrence of crane accidents on construction sites with multinomial Logit modeling.
- ✓ Analyze the impact of different variables on the probabilistic models with respect to various types of crane accidents.

1.5. Thesis Organization

Section 1 of thesis will introduce the research and discuss the problem statement. It will also clarify the research objectives.

Section 2 will include a review of the available literature on crane accidents and probabilistic models of accidents in other spheres of life such as road accident. The section also includes an introduction to previous research of mathematical models for crane operations. Section 2 will continue with a discussion about the characteristics of the different types of crane accidents. The last part of the section will discuss the conclusions and importance of using multinomial Logit models.

Section 3 will focus on data collection. The section shows the data samples from each year and the variables extracted from it. Descriptive analysis has been performed on all the variables and the findings have been shown graphically.

Section 4 discussed the methodology of the research. The section starts by discussing the coding as required by the statistical software package. After coding the output format has been explained and the division of crane accident types in to further sub-groups based on proximal cause, construction operation, organ affected and type of crane. Application of Logit modeling has been discussed and the last part explains the interpretation of the probability models and Significant tests which validate the models.

Section 5 will have the detailed results from the Logit modeling of the coded data for each and every accident type. Each accident type discusses the relationships and the meaning of values obtained for all the variables. The second part of the section describes the significant tests on the probability models.

Section 6 contains conclusions from this thesis along with recommendations for future research.

2. LITERATURE REVIEW

This section starts by discussing the literature reviewed on crane related fatalities in construction. The section also includes an introduction to different types of cranes involved in the accidents and also the proximal causes for crane accidents. Logit Modeling has also been reviewed and its use in figuring the probabilities. The last part of the section discusses the methods and mathematical model currently being used in the construction industry on the selection of cranes.

2.1 Analysis of Crane Accidents

Numerous studies have taken place in the last quarter century. For the most part, these studies fall into one of two categories:

1. Conceptual; or

2. Empirical.

The study of the past research has shown that even some "conceptual" studies often do contain some data; their focus is on possible human factors or equipment issues rather than on the statistical details of fatality cause (Beavers, Moore, Rinehart, & Schriver, 2006). A prime example of studies of this kind is the (MacCollum, 1993) study which can be characterized as a hazard analysis of crane design. MacCollum's conclusions are primarily suggestions with respect to technical designs of cranes and the operations they are selected for. Another study has shown the causes and prevention of crane accidents. (Jarasunas, 1984-1985) In his second paper he concludes his prevention research with the observation that "from a safety engineering view point, the first priority is to make the tools and equipment as safe as possible through the application of known state-of-the-art.”

Jarasunas’ research in 1984 might have some different factors to consider henceforth his conclusions were different and contrary to him, some contributors to the literature have made specific suggestions regarding operator training. For example, (Neitzel & Seixas, 2001) reviewed crane safety in the construction industry and pointed out there is currently no federal United States standard requiring construction crane operators to be licensed or certified.

The quantitative approach is the most popular when it comes to studies of safety culture (Beavers, Moore, Rinehart, & Schriver, 2006). The greatest advantage of quantitative research designs is that they produce representative results that can be generalized. In this research, I have chosen probability models to make the research more extensive and co-relate more to variable construction site conditions. Probability models will inculcate both qualitative and quantitative aspects of the crane safety.

ASCE task committee has published a manual entitled Crane safety on construction sites (Sale, 1998). Within the manual, ASCE published ASCE Policy Statement 424 which made eight safety recommendations in crane operations.

(Hakkinen, 1993), in a paper on crane accidents in general, points out that as far as training goes, the education of all workers in the crane environment is important. In his limited data base he found that “most of the accident victims were workers fastening or loosening loads or steering loads with their hands during lifting.”

Two recent studies can be characterized as primarily empirical. In the first of these, (Suruda, Egger, Liu, & Liu, 1997) examined the IMIS database of crane fatalities for the years 1984–1994 and estimated that OSHA had investigated 502 deaths in 479 events. Using the same data base of OSHA fatality narratives, as Suruda, and for essentially the same time period, (Shepherd, Kahler, & Cross, 2000) established taxonomy for over 550 crane fatalities.

(Naevestad, 2008), has done a purely subjective study by interviewing the crane operators and process operators in which he has not referred to any historical data, instead has made a conjecture relying on the information provided by the interviewees.

2.2 Types of Cranes

“Cranes are available in a myriad of types and sizes, and no specific crane is the correct choice for a specific choice.” (Shapira & Schexnayder:, 1999). It is has been typically claimed that only logical review of technical factor is an important factor while selecting crane but there are more obscure considerations which should be taken care off (Glascock & Shapira, 1996).

(Laufer, Shapira, Cohenca-Zall, & Howell, 1993), who examined the depth of involvement in construction planning, reached similar conclusions to Glascock and

Shapira. Results were similar with respect to the changing participation level of the various parties throughout project life.

It is important to understand the selection of crane before predicting the probability of an accident happening because of the variability's involved in the process and the use. If only logical review of technical factors was the sole reason for selection then the output might have resulted in just one type of crane thereby diminishing the role of type of crane in predicting the accident probability. Hence, after the review of the previous literature it becomes important to understand the types of cranes involved in the accidents from year 2000 to 2006 and also include them as one of the variables while calculating the probability.

Some of the cranes which encompass the accident data issued by OSHA are shown in Figures 1-7.:

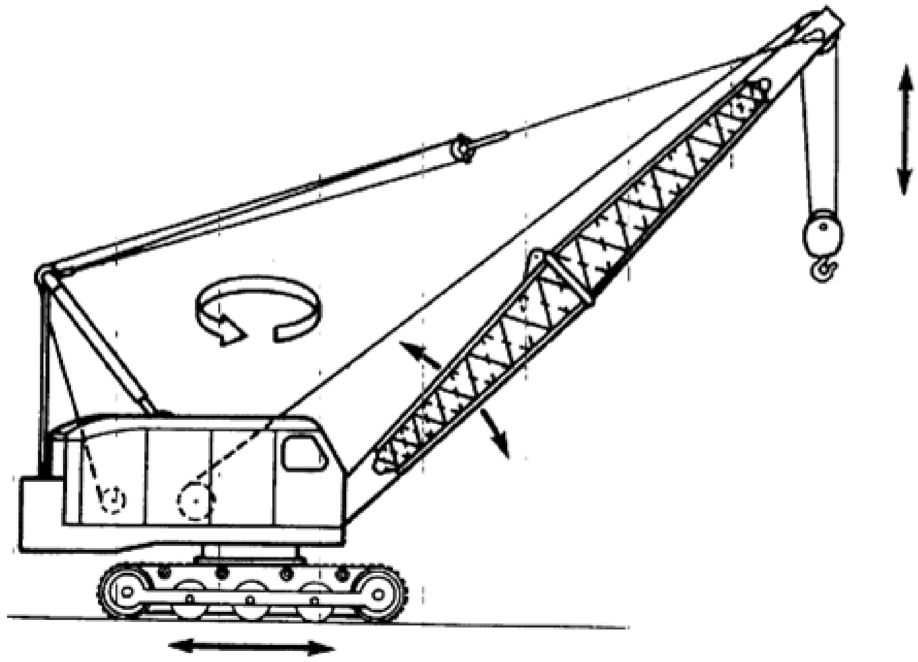

Figure 1 Illustration Shows Crawler-mounted Latticework Boom Crane (Source- NOAA)

“A crawler is a crane mounted on an undercarriage with a set of tracks (also called crawlers) that provide stability and mobility.” **(CMAA)**

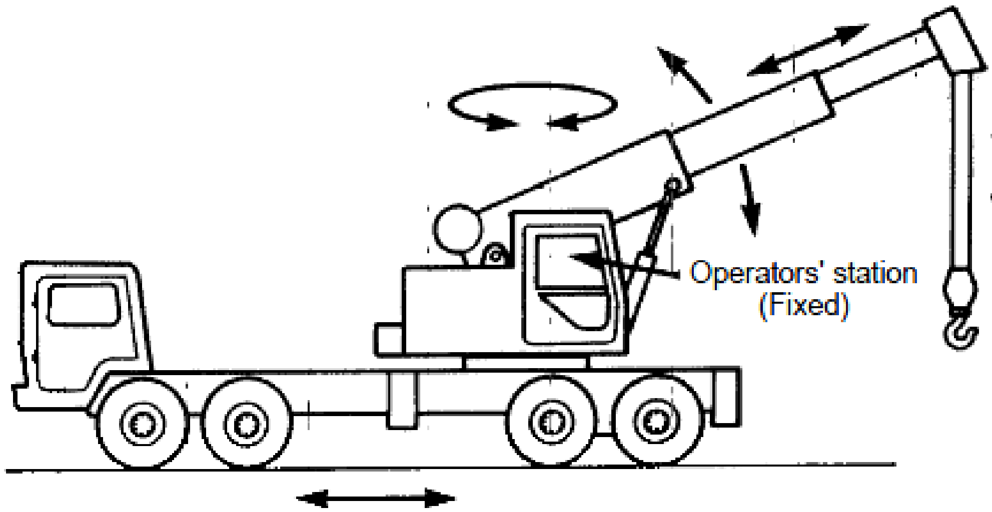

Figure 2 Illustration Shows Mobile Truck Crane (Telescoping Hydraulic Boom) (Source-NOAA)

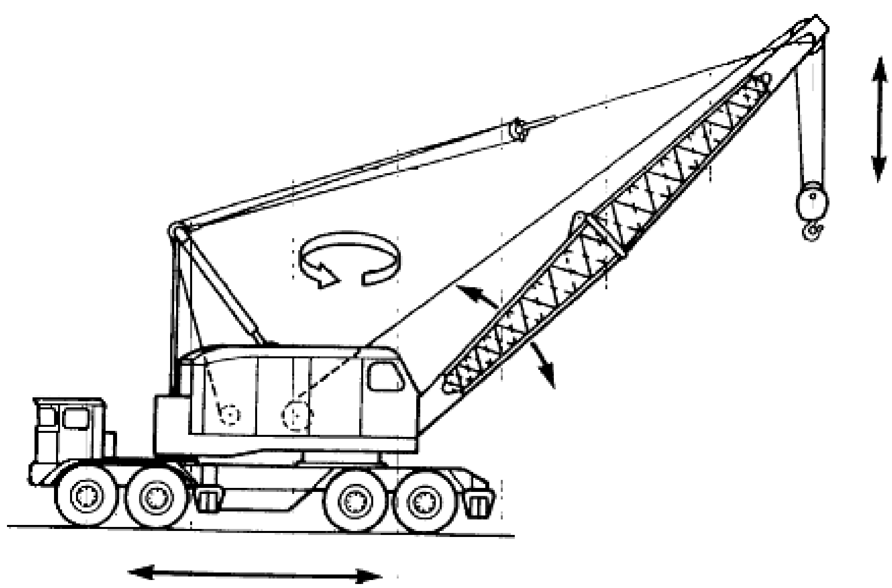

Figure 3 Illustration Shows Mobile Truck Crane (Latticework Boom) (Source- NOAA)

Figures 2 and 3 show mobile truck cranes defined as “A crane mounted on a truck carrier provides the mobility for this type of crane.” (CMAA)

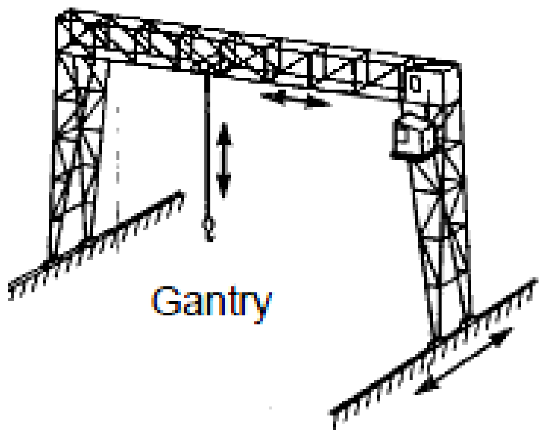

Figure 4 Illustration shows Gantry Crane (Source-NOAA)

Figure 4 shows a gantry crane defined as “A gantry crane has a hoist in a fixed machinery house or on a trolley that runs horizontally along rails, usually fitted on a single beam (mono-girder) or two beams (twin-girder)” (CMAA).

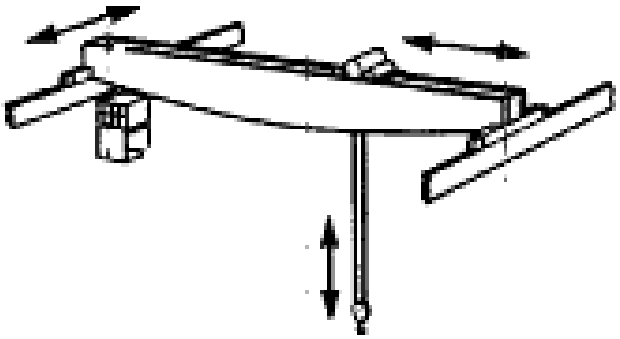

Figure 5 Illustration Shows Bridge Crane (Source-NOAA)

Bridge crane shown in Figure 5 is same as a gantry crane with a small difference that the horizontal movement takes place on the parallel horizontal beams rather than with rollers on ground which is the case with gantry crane.

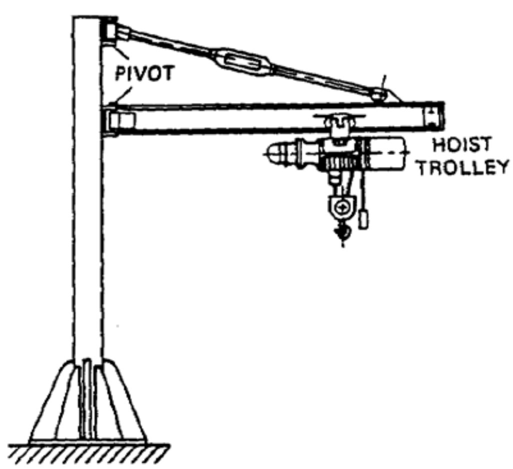

Figure 6 Illustration Shows Jib Crane (Source- NOAA)

Jib crane shown in Figure 6 is defined as “A type of crane where a horizontal member (jib or boom), supporting a moveable hoist, is fixed to a wall or to a floor-mounted pillar.” (CMAA).

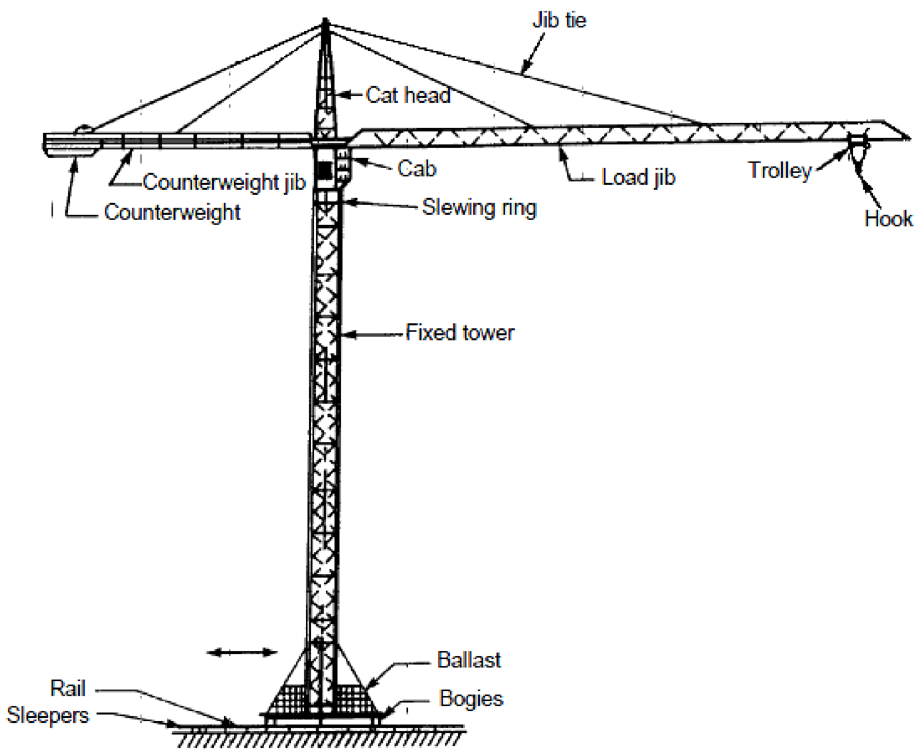

Figure 7 Illustration Shows Tower Crane (Source- NOAA)

Tower Crane shown in Figure 7 is a lifting device which is generally attached to the ground and sometimes to the sides of the structures and uses counterweight to balance itself while transferring load.

As per (Shapira & Schexnayder:, 1999) equipment planning is not a one-time act but an ongoing process that is conducted throughout the project life. Hence the use of crane type can be changed with the probabilities of an accident happening.

2.3 Summary

Study of previous crane accident analysis indicates that researchers have been interested either determining the figurative or subjective analysis. The stress has been laid on the taxonomic analysis by the virtue of data collected from OSHA/Bureau of Labor Statistics. Suggestions have been made purely on the basis of the percentages or type of accidents identified from the OSHA database. There has been no reference anywhere in which format the data was collected or what were the criteria's while analyzing the data from OSHA. There have been no statistical modeling or significance tests that have been applied as far as crane accidents are concerned. Another thing to be noted is the analysis of only fatal accidents.

Literature study also finds some studies on various type cranes involved in accidents and the parameters involved in their selection. There have been some statistical models and methods that have been researched upon but nobody has been able to show their use in the pragmatic scenario. (Beavers, Moore, Rinehart, & Schriver, 2006) and (Shapira & Schexnayder:, 1999) have included various crane types in their study. (Beavers, Moore, Rinehart, & Schriver, 2006), have also included the various occupations that are involved in crane accidents.

2.4 Application of Mathematical Models

There are no instances of mathematical models that are being applied as far as the selection of the cranes (Shapira & Schexnayder:, 1999). Their research show that decisions have been managerial in nature and engineering is an afterthought. Although there are researches' that have shown the utilization of mathematical models can be profitable for the construction industry both economically and feasible with regard to safety (Al-Humaidi & Tan:, 2008).

(Al-Humaidi & Tan:, 2008), has shown fuzzy modus ponens deduction techniques incorporating rotational and angular fuzzy-set models, which approximate subjective judgment. Subjective judgment is commonly used to establish the relation between the construction operation and likelihood of fatal accidents. Among the various procedures for analyzing the causes of crane-related electrocution are

(1) Deterministic,

(2) Non-deterministic probabilistic, and

(3) Non-deterministic fuzzy methods.

The deterministic approach analyses the historical data involving technical and procedural problems. (Liao, 1995) Hence, in a project that involves operation of cranes, preventive acts and procedures are taken to minimize or eliminate any source of hazard. The nature of construction projects sometimes involves temporary and unprecedented activities, and the availability of historical data about similar scenarios becomes questionable. Accordingly, this approach may overlook the many uncertainties that may be encountered on construction sites.

Nondeterministic probabilistic approaches examine the reliability of a system based on quantitative/statistical data. Since crane related accidents are often unique and involve numerous variables, the probability approach to assessing the likelihood of a crane tip over as a result of overloading requires historical data that can be used.

On the other hand, the non-deterministic fuzzy-set approach for crane safety requires primarily the subjective judgment of domain experts. For example, with respect to electrocution accidents, a clear distance between the overhead power line and components of the crane may involve linguistic terms such as ‘‘clear distance is very short, short, or fairly short.” The fuzzy-set approach can be implemented to transform such linguistic terms into quantitative mathematical representations (Al-Humaidi & Tan:, 2008).

2.4.1 Fuzzy Logic

Since (Zadeh, 1965), introduced the concept of a fuzzy set, it has been employed in numerous areas. The concept is founded on the fact that some notions, though meaningful, may not be clearly defined. Application of fuzzy logic is based on a membership function that lies over a range of numbers between 0 and 1. Assigning quantitative values to linguistic terms is the first step of using fuzzy logic (Al-Humaidi & Tan:, 2008).

For example, to determine the likelihood that a mobile crane will contact an overhead power line, the fuzzy logic assigns a membership value to an element. The membership value describes the strength of the element’s membership in the set. Membership values range from 0, indicating non-membership to 1, which indicates absolute membership. If the likelihood of electrocution is high in an expert's judgment, the term high can be assigned a membership value in the set of likelihood of electrocution, and can be written symbolically as l (high), where l is the membership function that has a value between 0 and 1. The fuzzy concept of likelihood of accident can be further extended into high, fairly high, very high, low, fairly low, and very low. Similarly, fuzzy logic can be applied to the set of clear distances between the mobile crane and overhead power lines, where concept of membership values include short, fairly short, very short, long, fairly long, and very long. For example, if the clear distance between the mobile crane and overhead power line is short, this term is a member of the clear distance set and can be written symbolically as l (short), where l is a membership function that returns a value between 0 and 1.

Fuzzy models are classified into two categories i.e. translational and rotational models. (Al-Humaidi & Tan:, 2008), describes these models as subjective judgments captured with membership functions with linguistic values and ramp membership respectively. These methods have been mathematically defined in Baldwin's fuzzy rotational model. The implementation of Baldwin's fuzzy rotational model is a three step process.

1) The inverse truth functional modification (TFM) is conducted.
2) Lukasiewicz implication rule is applied to get the truth value of high likelihood.
3) TFM, a logical operation which modifies the membership function of a fuzzy set with known truth values.

Baldwin's rotational model uses a graphical procedure to show the results of these steps as shown in Figure 8 (Al-Humaidi & Tan:, 2008).

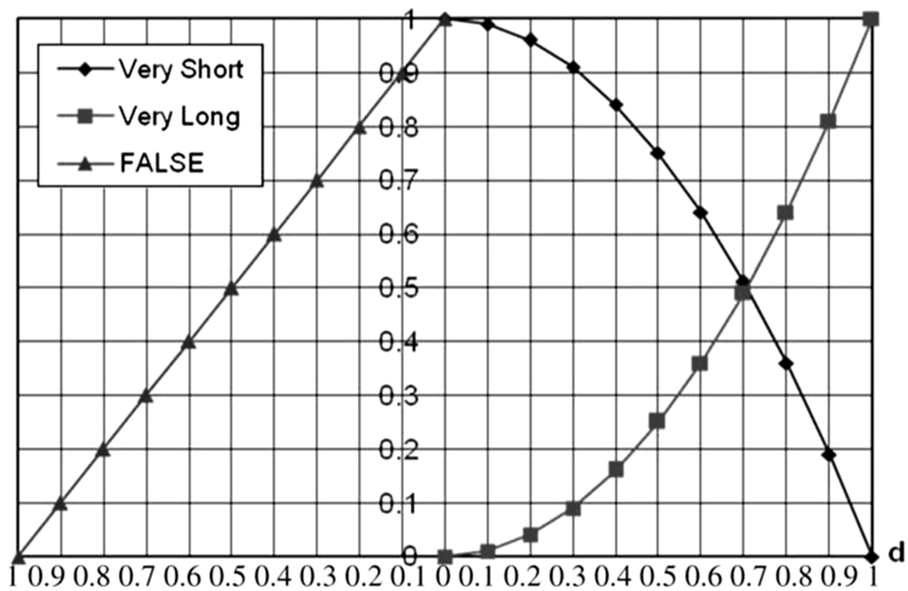

Figure 8 Truth Function Modification (TFM) Operation

Figure 8 (Al-Humaidi & Tan:, 2008) on the right hand side shows the likelihood of safe clear distance with respect to the probability of crane touching the wire. On the left hand side, the axis is representing the fuzzy elements.

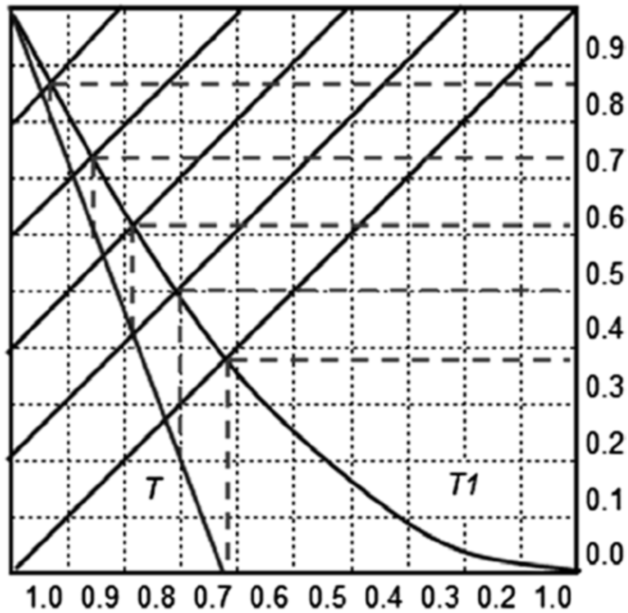

Figure 9 Graphical Representation of LIR

Figure 9 (Al-Humaidi & Tan:, 2008) analyzes the membership function with respect to truth elements.

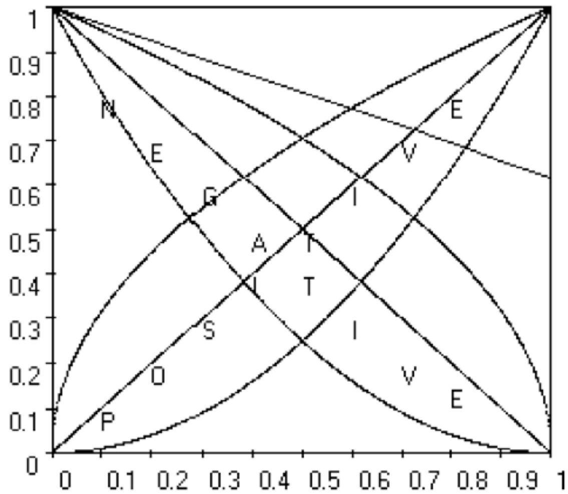

Figure 10 The Baldwin Model

Finally, de-fuzzification (ranking of the linguistic values) of the result is obtained by comparing Likelihood value to Baldwin's rotational model as shown in Figure 10. Even after applying these models Al-Humaidi and Tan were not able to conclude something concrete and hence recommended further analysis. But it must be mentioned that they have strongly recommended the use of linguistic values to express subjective judgment in construction is paramount. Hence, the study of another option or mathematical model is necessary and in this research Logit modeling suits the best and the reasons for the same would be defined in the coming sections.

2.5 Logit Modeling

2.5.1 Concept

As per (Menard, 2009) "Binary (or binomial) logistic regression is a form of regression which is used when the dependent is a dichotomy and the independents are of any type. Multinomial logistic regression exists to handle the case of dependents with more classes than two, though it is sometimes used for binary dependents also since it generates somewhat different output."

Logistic regression can be used to predict a dependent variable on the basis of continuous and/or categorical independents and to determine the percent of variance in the dependent variable explained by the independents; to rank the relative importance of independents; to assess interaction effects; and to understand the impact of covariate control variables. The impact of predictor variables is usually explained in terms of odds ratios.

(Aldrich & Nelson, 1984), explains that logistic regression applies maximum likelihood estimation after transforming the dependent into a Logit variable (the natural log of the odds of the dependent occurring or not). In this way, logistic regression estimates the odds of a certain event occurring. It must be noted that logistic regression calculates changes in the log odds of the dependent, not changes in the dependent itself as OLS regression does (Hosmer & Lemeshow, 2000).

Logistic regression has many analogies to OLS regression: logit coefficients correspond to 'b' coefficients in the logistic regression equation, the standardized logit coefficients correspond to beta weights, and a pseudo R^2 statistic is available to summarize the strength of the relationship. (Aldrich & Nelson, 1984) have shown that unlike OLS regression, logistic regression does not assume linearity of relationship between the independent variables and the dependent, does not require normally distributed variables, does not assume homoscedasticity, and in general has less stringent requirements. It does, however, require that observations be independent and that the independent variables be linearly related to the Logit of the dependent. The predictive success of the logistic regression can be assessed by looking at the classification table, showing correct and incorrect classifications of the dichotomous, ordinal, or polytomous dependent. Goodness-of-fit tests such as the likelihood ratio test are available as indicators of model appropriateness, as is the Wald statistic to test the significance of individual independent variables.

(Hosmer & Lemeshow, 2000), have explained that for polytomous dependent variable, the logistic regression model may be calculated as a particular form of the multinomial logit model. They have also stated that “Mathematically, the extension of the dichotomous logistic regression to polytomous dependent variable is straightforward.” One value of the dependent variable is designated as a reference category, and the probability of membership in reference category is compared to other categories. For ordinal variables, contrasts may be made with successive categories

Adding to this theory (Menard, 2009), has shown that for dependent variables with some number of categories, M, for example then logit model requires the calculation of M-1 equations for each category relative to the reference category which describes the relationship between dependent variable and independent variable. He also states that “As long as we keep the same set of categories and the same predictors for the model, the choice of one category will have no impact on the statistics for the overall model.”

(Reynolds, 1984), states that logit modeling provides choice between quantitative and qualitative indices of explained variations, and careful consideration should be given to as to whether the interest is in how close the predicted probabilities of category membership are to observed category membership or the concern is whether the prediction of category membership is correct or not. Then significance tests become very important in determining the appropriate variables and methods for right decisions to be taken.

2.5.2 Significance Tests for Multinomial Logistic Regression

Significance tests analyze the importance of various variables with respect to the dependent variable. (Menard, 2009), has recommended the likelihood ratio test over others.

The likelihood ratio test, also called the log-likelihood test, is based on -2LL (deviance). The likelihood ratio test is a test of the significance of the difference between the likelihood ratio (-2LL) for the researcher's model minus the likelihood ratio for a reduced model. This difference is called "model chi-square." (Munizaga & Alvarez-Daziano, 2005) The likelihood ratio test is generally preferred over its alternative, the Wald test. (Munizaga & Alvarez-Daziano, 2005)There are three main forms of the likelihood ratio test: While describing these forms Scott Menard's book on logistic regression has been referred.

1. Models. "Two models are referenced in the "Model Fitting Information" table above: (1) the "Intercept Only" model, also called the null model; it reflects the net effect of all variables not in the model plus error; and (2) the "Final" model, also called the fitted model, which is the researcher's model comprised of the predictor variables; the logistic equation is the linear combination of predictor variables which maximizes the log likelihood that the dependent variable equals the predicted value/class/group. The difference in the -2 log likelihood (-2LL) measures how much the final model improves over the null model" (Aldrich & Nelson, 1984).

Test of the overall model. "The likelihood ratio test of the overall model, also called the model chi-square test. When the reduced model is the baseline model with the constant only (a.k.a., initial model or model at step 0), the likelihood ratio test tests the significance of the researcher's model as a whole. A well-fitting model is significant at the .05 level or better, as in the figure above, meaning the researcher's model is significantly different from the one with the constant only. That is, a finding of significance ($p<=.05$ is the usual cutoff) leads to rejection of the null hypothesis that all of the predictor effects are zero. When this likelihood test is significant, at least one of the predictors is significantly related to the dependent variable." (Menard, 2009) In other words, the likelihood ratio test tests the null hypothesis that all population logistic regression coefficients except the constant are zero. And put a final way, the likelihood ratio test reflects the difference between error not knowing the independents (initial chi-square) and error when the independents are included in the model (deviance). When probability (model chi-square) <= .05, the null hypothesis is rejected knowing that the independents makes no difference in predicting the dependent in logistic regression.

The likelihood ratio test looks at model chi-square (chi square difference) by subtracting deviance (-2LL) for the final (full) model from deviance for the intercept-only model. Degrees of freedom in this test equal the number of terms in the model minus 1 (for the constant). This is the same as the difference in the number of terms between the two models, since the null model has only one term. Model chi-square measures the improvement in fit that the explanatory variables make compared to the null model (Munizaga & Alvarez-Daziano, 2005).

Although, if the log-likelihood test statistic shows a small p value (<=.05) for a model with a large effect size, contrary findings can be ignored based on the Wald statistic, it is biased toward Type II errors in such instances - instead good model fit overall can be assumed. (Lee, Shin, Park, & Ryu, 2009).

A common use of the likelihood ratio test is to test the difference between a full model and a reduced model dropping an interaction effect. If model chi-square (which is -2LL for the full model minus -2LL for the reduced model) is significant, then the interaction effect is contributing significantly to the full model and should be retained (Menard, 2009).

The likelihood ratio test assesses the overall logistic model but does not tell us if particular independents are more important than others (Duncan, Khattak, & Council, 1998). This can be done, however, by comparing the difference in -2LL for the overall model with a nested model which drops one of the independents. The likelihood ratio test can be used to drop one variable from the model to create a nested reduced model (Duncan, Khattak, & Council, 1998). In this situation, the likelihood ratio test tests if the logistic regression coefficient for the dropped variable can be treated as 0, thereby justifying dropping the variable from the model.

A non-significant likelihood ratio test indicates no difference between the full and the reduced models, hence justifying dropping the given variable so as to have a more parsimonious model that works just as well. Note that the likelihood ratio test of individual parameters is a better criterion than the alternative Wald statistic when considering which variables to drop from the logistic regression model.

2.5.3 Interpreting Probability Models

(Liao, 1995), explains the procedure of interpreting logit models in detail. The first and primary criteria is that the model itself must fit the data i.e. the model must be able to explain the response variable significantly better than the model with the intercept only. In such polytomous-response model, the category is in the dependent variable and truly discrete, nominal or unordered.

The multinomial logit model estimates the effects of explanatory variables on a dependent variable with unordered response categories: (Liao, 1995) further shows the basic equation required for the multinomial logit model which is as follow-:

$$Prob(\mathrm{y} = \mathrm{j}) = \frac{\sum_{\mathrm{e}^{\mathrm{k}=1}}^{\mathrm{k}} \beta_{\mathrm{jk}} \mathrm{x}_{\mathrm{k}}}{1 + \sum_{\mathrm{j}=1}^{\mathrm{J}-1} \mathrm{e}^{\sum_{\mathrm{e}^{\mathrm{k}=1}}^{\mathrm{k}} \beta_{\mathrm{jk}} \mathrm{x}_{\mathrm{k}}}} \tag{1}$$

The equation 1 (Liao, 1995) gives the Prob(y=j) where j= 1, 2, 3, ……., J-1. The parameters β have two subscripts in the model, ‘k’ for distinguishing ‘x’ variables and ‘j’ for distinguishing response categories.

All these equations are solved by SPSS and a user friendly output is provided with all the significant values such as Wald statistic, p-value and the standard error. Analysis of all these values provides the framework to design the probability model and refine it by deleting outliers and uncorrelated errors.

There are several rules that have been suggested by (Hosmer & Lemeshow, 2000) which should be considered when interpreting the coefficients in the MNL model.

- Alternative specific constants can only be included in MNL models for n-1 alternatives. Characteristics of decision-makers, such as socio-economic variables, must be entered as alternative specific. Characteristics of the alternative decisions themselves, such as different types of occupations, can be entered in MNL models as “generic” or as alternative specific.

- Variable coefficients only have meaning in relation to each other, i.e., there is no ‘absolute’ interpretation of coefficients. In other words, the absolute magnitude of coefficients is not interpretable like it is in ordinary least squares regression models.

- Alternative Specific Constants, like regression, allow some flexibility in the estimation process and generally should be left in the model, even if they are not significant.

- Like model coefficients in regression, the probability statements made in relation to t-statistics are conditional.

2.6 Summary of Literature Review

A review of the literature reveals that research on crane accidents has been merely figurative and there has been no instance of analyzing statistical significance or co-relation between the numerous variables involved as far operations of crane is concerned in construction industry. Latest set of crane accidents reports available belong to 1990-2002. These reports indicate that most number of fatalities have occurred due to electrocution. These studies also mention that mobile truck crane has been involved in most number of fatalities. But there is no correlation of mobile crane and electrocution. Literature review of numerous papers and reports also show that non-fatality accidents have been ignored.

There has been some research on the application of mathematical models as far as selection of cranes is concerned, but the results show that in current scenario it is very subjective in spite of being a technical issue. Fuzzy logic is the only another form of mathematical model that has been used to figure out significance and correlation in accidents and cranes. The literature review of crane accidents definitely encourages the use of more extensive research techniques which has the ability to analyze and correlate large number of variables involved in crane accidents.

Study of statistical methods helps to identify the appropriate methodology and techniques which can be used to identify probabilities on the occurrence of crane accidents based on yester year data and trends. The current study is in the mold of the empirical studies as discussed above in literature review. It differs from them in several respects, however. In the first place the data base involves the years 2000–2006, whereas the other studies ended in 1994 - 2002, respectively. Second, the data in the early studies were based upon the IMIS narrative reports while this thesis has investigations available from the full OSHA case files which provided information not in the narrative.

Considerable researches in road accidents have been undertaken by using Logit models. (Duncan, Khattak, & Council, 1998). Applying the ordered probit model to injury severity in truck-passenger car rear-end collisions (Transport. Res.Rec. 1635, 63–71.). These models have aided the road safety professionals in visualizing the hazard factors associated with road accidents for future design purposes as well as safety procedures.

Similarly, there is a scope of applying Logit models for the beneficiary of professionals on crane safety.

These mathematical models may be further be used for computer simulations to identify the hazards. (Munizaga & Alvarez-Daziano, 2005) Crane-related fatalities are substantial, representing more than 8% of all construction fatalities investigated by OSHA, and most if not all are preventable. “Census of fatal occupational injuries summary 2003.” (Census of Fatal Occupational Injuries, 2008). There have been efforts by other arenas for society to undertake such initiatives such as transportation (O’Donnell & Connor, 1996). Predicting the severity of motor vehicle accident injuries using models of ordered multiple choices have been successful in minimizing. Hence it would be wise to use a validated statistical theory which may prove to be beneficial for construction professionals to minimize crane accidents.

3. DATA

3.1 Data Collection

The only validated source of data available is U.S. Department of labor statistics which does In support of its analysis of the IMIS records; CIRPC developed a mutually exclusive list of 29 proximal cause codes of fatal construction events. Each fatal event occurring during the study period was classified and ranked by proximal cause and annual reports were submitted to OSHA (Schriver & and Schoenbaum, 2003).

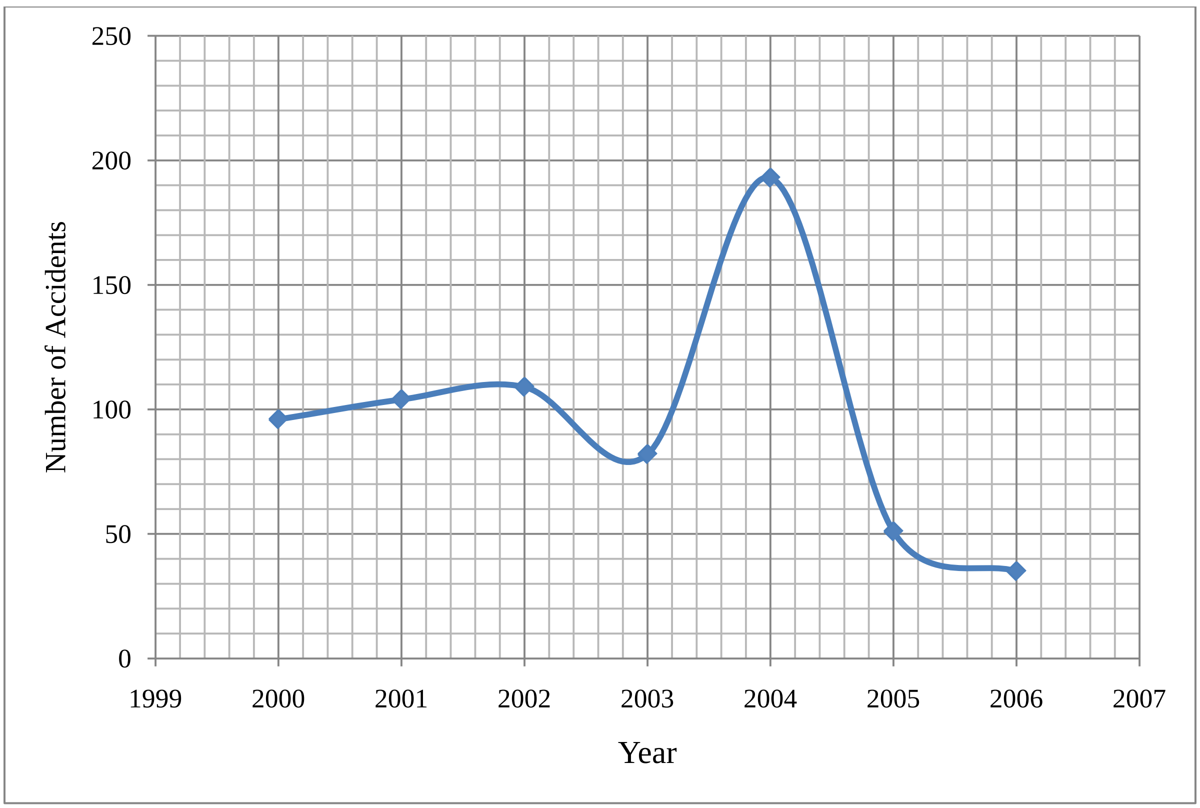

Figure 11 Frequency of Crane Accidents from 2000 to 2006

Figure 11 shows the number of crane accidents that have happened from 2000 to 2006.

3.2 Data Samples

All the accident inspections have an inspection number which is an online link to the U.S. Department of Labor Statistics website (OSHA, Homepage, 2010). All the accidents have been sorted by the date they happened and have been specified with SIC. Generally all the variables required for the analysis can be derived after reading the report. Inspection also shows the keywords which help in identifying key variables for the research. Occupation, construction operation and degree of accidents are key variables as far as probability model is concerned and detailed information has been provided for them. All the reports are consistent but there were some instances where the inspector did not have a great deal of information about the accident and hence most the variables were absent and accident had to be ignored from the data.

Tables 1-7 show the format and methodology used by OSHA to inspect the accidents. These random samples represent an accident from each year 2006 to 2001, just to show the consistency of the inspections and their documentation.

Table 1 Accident Inspection (2006)

Accident: 201087483 -- Report ID: 0950625 -- Event Date: 05/11/2006			
Inspection	Open Date	SIC	Establishment Name
306361809	05/12/2006	0782	Fresno Landscaping, Inc.

Table 1 Continued

On May 11, 2006, Employee #1 was working as part of a crew moving olive trees for transporting and planting in the yard of a single family home. The trees were in wood planters that measured 5 feet by 5 feet by 31 inches tall. The trunks of the trees measured approximately 44 to 48 inches in circumference and they weighed between 5,000 to 6,000 lbs. The equipment being used was a JLG commercial truck mounted hydraulic crane, Model Number 800BT, Serial Number 0408801343, and License Number 4B81980. The crane, which was purchased in March of 2006 and had a rated capacity of 16,000 lbs., was being operated by the CEO, who was also the site supervisor. While the truck mounted hydraulic truck was positioned on a dirt access road out of the way of main traffic, the operator was on the operator's platform. Employee #1 attempted to turn and run out of the way, but he the crane fell and pinned him underneath the mast. Emergency services were called, and Employee #1 was taken to Sierra Kings Hospital, where he was determined dead. The accident investigation revealed that the outrigger was not fully extended, allowing uneven weight distribution and causing the unit to tip over. The Employer was cited for being in violation of the California Code of Regulations.
Keywords: crane, overturn, unstable load, struck by, pinned, caught between, chest, falling object, hoisting mechanism

	Inspection	Degree	Nature	Occupation
1	306361809	Fatality	Other	Laborers, except construction

Variables for this accident are as follow-:

Fault-	Manual
Degree-	Fatality
Accident type-	Crane Tip Over
Construction Operation-	Lifting/Moving equipment and material
Contributing Factors-	Improper Operation
Victim's Occupation-	Others
Organ Affected-	Chest
Load-	Loaded
Type of Crane-	Mobile Truck Crane

Table 2 Accident Inspection (2005)

Accident: 201125721 -- Report ID: 0950613 -- Event Date: 09/13/2005					
Inspection	Open Date	SIC	Establishment Name		
300843489	09/13/2005	1622	R.M. Harris		
At approximately 9:30 a.m. on September 13, 2005, an employee was working with a small crew of men, moving steel beams from the ground to a highway overpass. The employee was operating a hydraulic boom crane, and was lifting a 50-ft long steel beam weighing approximately 5,400 lb. This exceeded the safe working load for the crane. As the load was raised off the ground, the crane tipped over on its outriggers, and fell from the overpass to the ground below, destroying the crane. The crane operator survived with minor cuts and did not require hospitalization.					
Keywords: crane, hydraulic crane, steel beam, unstable load, falling object, crane outrigger, crane operator, laceration, face					
End Use	Project Type	Project Cost	Stories	NonBldgHt	Fatality
Bridge	New project or new addition	$5,000,000 to $20,000,000		24	

Table 2 Continued

	Inspection	Degree	Nature	Occupation	Construction
1	300843489	Non Hospitalized injury	Cut/Laceration	Engineer	Cause: Placing bridge deck Fat Cause: Lifting operations

Variables for this accident are as follow-:

Fault -	Manual
Degree -	Non-Fatality
Accident type -	Crane Tip Over
Construction Operation -	Lifting/Moving equipment and material
Contributing Factors -	Improper Operation
Victim’s Occupation -	Engineer
Organ Affected -	Head
Load -	Loaded
Type of Crane -	Mobile Truck Crane

Table 3 Accident Inspection (2004)

Accident: 202344305 -- Report ID: 0420600 -- Event Date: 02/24/2004			
Inspection	Open Date	SIC	Establishment Name
307402917	02/24/2004	1622	Granite Construction Company Of California
On February 23, 2004, Employee #1 and a coworker were involved in piling driving operation and were using a crane to set the leads around a pile. The crane operator noticed that the cushion came off from the bottom of the hammer assembly. He lowered the hammer in an effort to push the cushion back into place. By lowering the hammer, the pile was hit at the top and off center, causing pieces of concrete to be sheared off from the top of the pile and fall to the ground. Employee #1 and a coworker were standing on top of the template guiding the leads in place and around the pile when Employee #1 was struck on his head. That caused him to fall off the template to the ground. Employee #1 was killed. The coworker jumped off the template to the ground. The template was a steel structure made of "I" beams and was used to mark the location that the concrete piles would be driven. The "template" measured 10 ft 5 in. from the ground and was 16-ft wide and 4-ft long.			
Keywords: construction, crane, piling, pile leads, tower crane, concrete, struck by, head, fall, fracture			

Table 3 Continued

End Use	Proj Type	Proj Cost	Stories	NonBldgHt	Fatality
Bridge	New project or new addition	$20,000,000 and over			X

	Inspection	Degree	Nature	Occupation	Construction
1	307402917	Fatality	Fracture	Labor	FallHt: Cause: Pile driving FatCause: Struck by falling object/projectile

Variables for this accident are as follow-:

Fault-	Manual
Degree-	Fatality
Accident type-	Fall
Construction Operation-	Pile Driving
Contributing Factors-	Improper Operation
Victim’s Occupation-	Labor
Organ Affected-	Head
Load-	Loaded
Type of Crane-	Tower Crane

Table 4 Accident inspection (2003)

Accident: 200372563 -- Report ID: 0454510 -- Event Date: 07/26/2003					
Inspection	Open Date	SIC	Establishment Name		
306082843	07/28/2003	1791	Basic Construction & Development		
On July 26, 2003, Employees #1 and #2 were erecting structural steel and metal decking for a breezeway at an elementary school. A bundle of metal decking 10 ft 9 in. long, weighing approximately 840 lbs, was being hoisted by a truck-mounted crane onto the structure. Employees #1 and #2 were both on 8-ft stepladders set up on opposite sides of the breezeway. The load was rigged with a single nylon strap choker positioned in the middle of the bundle. A tag line was on the load but apparently was not being used. After it was hoisted above the structure and above both employees, Employee #1 reached up and pushed one end of the bundle to rotate the load for correct positioning. The load shifted, struck the steel, and fell out of the rigging, striking Employee #2 in his foot. Employee #1 tried to hold the bundle up, but it fell onto him, causing an amputation.					
Keywords: struck by, load shift, suspended load, stepladder, construction, steel, decking panel, crane, foot, amputated					
End Use	Proj Type	Proj Cost	Stories	NonBldgHt	Fatality
Other building	New project or new addition	\$50,000 to \$250,000	10		

Table 4 Continued

	Inspection	Degree	Nature	Occupation	Construction
1	306082843	Non Hospitalized injury	Fracture	Structural metal workers	Cause: Erecting structural steel FatCause: Struck by falling object/projectile

Variables for this accident are as follow-:

Fault-	Manual
Degree-	Non-Fatality
Accident type-	Struck by Load
Construction Operation-	Erecting Structural Steel
Contributing Factors-	Improper Operation
Victim’s Occupation-	Labor
Organ Affected-	Foot
Load-	Loaded
Type of Crane-	Mobile Truck Crane

Table 5 Accident Inspection (2002)

Accident: 200352847 -- Report ID: 0453710 -- Event Date: 10/30/2002			
Inspection	Open Date	SIC	Establishment Name
305726473	10/30/2002	1799	Phoenix Fabricators & Erectors, Inc.
At approximately 10:50 a.m. on October 30, 2002, Employees #1 through #4 were constructing a 500,000-gallon water tower with a mobile crawler crane. While lifting the fourth section of the tank for cleaning prior to installation, the crane failed, causing two of the previously installed tank sections to partially collapse and another section to be suspended from the tower structure. Employee #1 fell approximately 85 ft onto the concrete foundation of one of the tower legs, sustained broken bones and a massive head injury, and was killed. Employee #2 fell approximately 85 to the ground, sustaining a head injury and broken bones, and died of his injuries 23 days later. Employee #3, who became pinned under a tank section, was hospitalized for shoulder injuries. Employee #4, who also became pinned under a tank section and suffered a sprain, freed himself and rendered aid to Employee #2. A coworker who remained on the tower during and after the collapse, indicated that fall protection harnesses were worn but they were not required to be tied off at all times.			
Keywords: fall, water, water tower, crane, derrick, collapse, fall protection, fracture, sprain			

Table 5 Continued

End Use	Proj Type	Proj Cost	Stories	NonBldgHt	Fatality
Tower, tank, storage elevator	New project or new addition	$500,000 to $1,000,000		85	X

	Inspection	Degree	Nature	Occupation	Construction
1	305726473	Fatality	Other	Occupation not reported	FallDist: 85 FallHt:85 Cause: Erecting structural steel FatCause: Fall from/with

Variables for this accident are as follow-:

Fault-	Technical
Degree-	Non-Fatality
Accident type-	Fall
Construction Operation-	Lifting/Moving equipment and material
Contributing Factors-	Boom Failure
Victim's Occupation-	Crane Operator
Organ Affected-	Head
Load-	Loaded

Table 6 Accident Inspection 2001

Accident: 170626386 -- Report ID: 0950621 -- Event Date: 08/20/2001					
Inspection	Open Date	SIC	Establishment Name		
125790170	09/04/2001	1623	Sierra National Construction		
At approximately 10:30 a.m. on August 20, 2001, Employee #1, a laborer, was working on a new sewer pipe and pumping station. A mobile truck crane had tipped over and Employee #1 was assisting in the effort to stabilize it. While trying to raise the crane, the load lines became entangled, Employee #1 decided to walk about 90 ft out the extended hydraulic boom to free the lines (wire cables). As he did so, the crane moved and the cable came free striking him. The force of the impact knocked him about 15 ft to the ground. Emergency medical services were summoned and he was transported to the hospital. At the hospital, he was treated for injuries including a broken elbow and dislocated ankle. He was hospitalized for a day and then released the following day.					
Keywords: crane, overturn, sewer, metal wire, entangled, fracture, elbow, dislocated, ankle					
End Use	Proj Type	Proj Cost	Stories	NonBldgHt	Fatality
Pipeline	New project or new addition	$500,000 to $1,000,000		20	

Table 6 Continued

	Inspection	Degree	Nature	Occupation	Construction
1	125790170	Hospitalized injury	Dislocation	Concrete and terrazzo finishers	Cause: Pouring concrete foundations and walls FatCause: Failure of cable

Variables for this accident are as follow-:

Fault-	Manual
Degree-	Non-Fatality
Accident type-	Failure of Cable
Construction Operation-	Assembly/Disassembly of crane
Contributing Factors-	Cable Snap
Victim’s Occupation-	Labor
Organ Affected-	Arm
Load-	Non- Loaded
Type of Crane-	Mobile Truck Crane

Table 7 Accident inspection (2000)

Accident: 201404019 -- Report ID: 0552651 -- Event Date: 03/09/2000					
Inspection	Open Date	SIC	Establishment Name		
127036986	03/09/2000	1542	Precast Services Inc		
Employees #1, #2, and #3, laborers, were injured when a cable on the tower crane parted and a double-tee beam fell on them. At the time of the accident Employee #1 was on a ladder below the double-tee, Employee #2 was riding the double-tee, and Employee #3 was coiling up the welding cable. Employees #1 and #3 sustained fractures on arms, and Employee #2 had bruises, contusions, and abrasions. They were not hospitalized.					
Keywords: fracture, struck by, flying object, abrasion, , construction, tower crane, wire rope					
End Use	Project Type	Project Cost	Stories	NonBldgHt	Fatality
heavy construction	New project	$500,000 to $1,000,000		90	

	Inspection	Degree	Nature	Occupation	Construction
1	127036986	Non Hospitalized injury	Fracture	Construction laborers	Cause: Erecting steel. Fat Cause: Struck by falling object.

Variables for this accident are as follow-:

Fault-	Technical
Degree-	Non-Fatality
Accident type-	Failure of Cable
Construction Operation-	Erecting Structural Steel
Contributing Factors-	Cable Snap
Victim's Occupation-	Labor
Organ Affected-	Arms
Load-	Loaded
Type of Crane-	Tower Crane

3.3 Descriptive Analysis

Numerous analysis of crane accidents in the past have identified the types of crane accidents (Beavers, Moore, Rinehart, & Schriver, 2006), in fact OSHA provides the keywords as far as accident types are concerned. Although, as far as determining the probability of an accident, not all the variables provided in the inspections are required. Examples of variables which are redundant for this research are gender, project cost, project type. From the analysis of 672 crane accidents inspections, potential causes of crane-related fatalities were identified. These proximal causes just compliment the previous research which performed a text search of the narrative information available in the IMIS database (Beavers, Moore, Rinehart, & Schriver, 2006). The only difference is that this research involves both fatality and non-fatality accidents.

Along with the proximal causes or accident types there were other factors which were identified as variables to be analyzed and important for predicting the probability of a crane accident. These factors are construction operation, contributing factors, crane types, load, victim’s occupation, organ affected. Selection of variables has been constrained by the inspection performed by the OSHA. As there is no other valid source of collecting the crane accident data, this research is depends entirely on methods used by OSHA to categorize various variables involved.

Figure 12 shows the division and categorization in which OSHA data has been analyzed for this research:

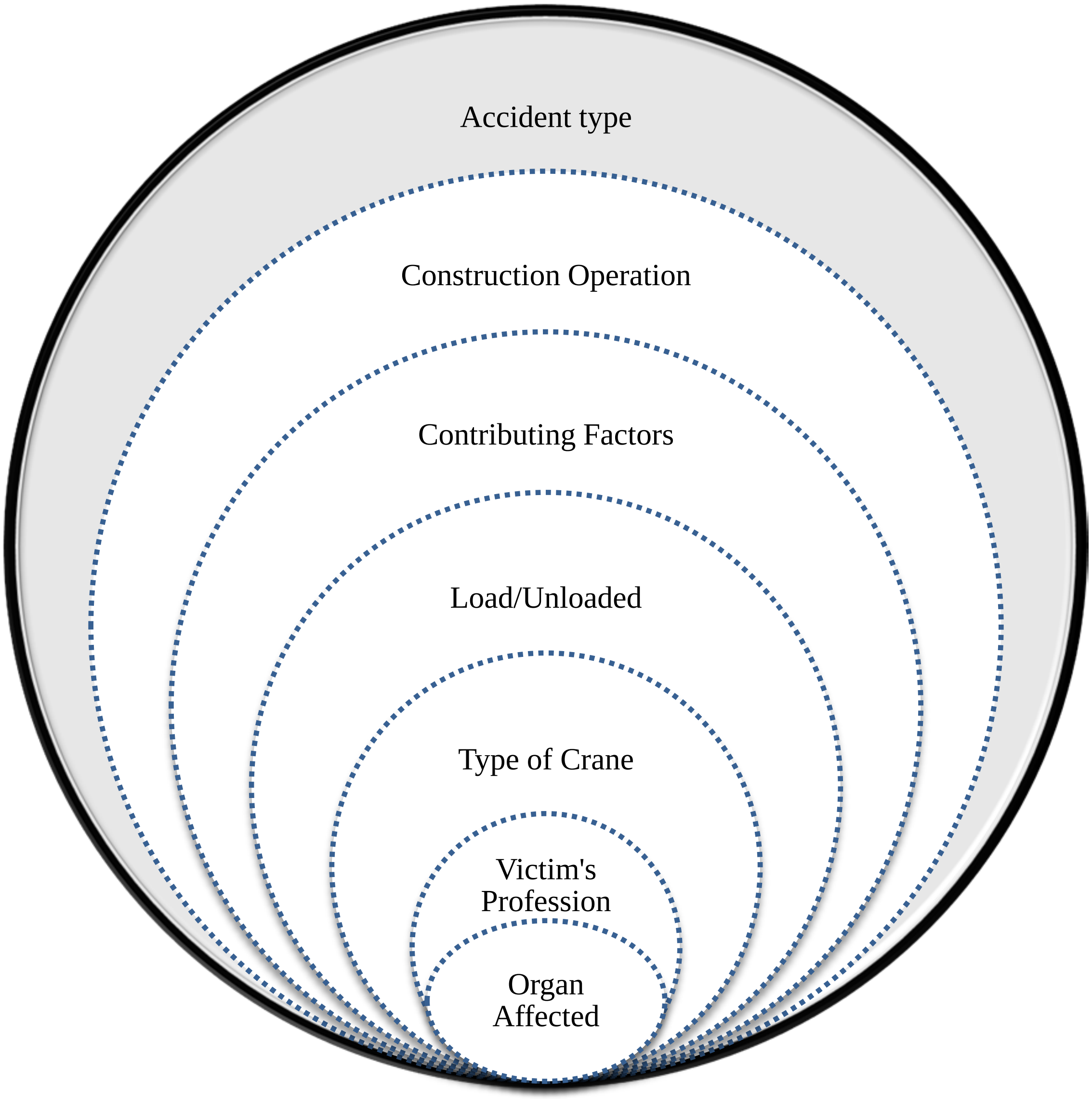

Figure 12 Venn Diagram for Derived Variables from Accidents Inspections

Analysis of all the above categories have shown that all the variables do not co relate with each other. Therefore efforts have been made to group them in appropriate permutations.

Following figure shows the various kinds of occupations involved in crane accidents. Category ‘Others’ includes the frequency of all those professions whose numbers are insignificant with respect to all the professions which have been mentioned.

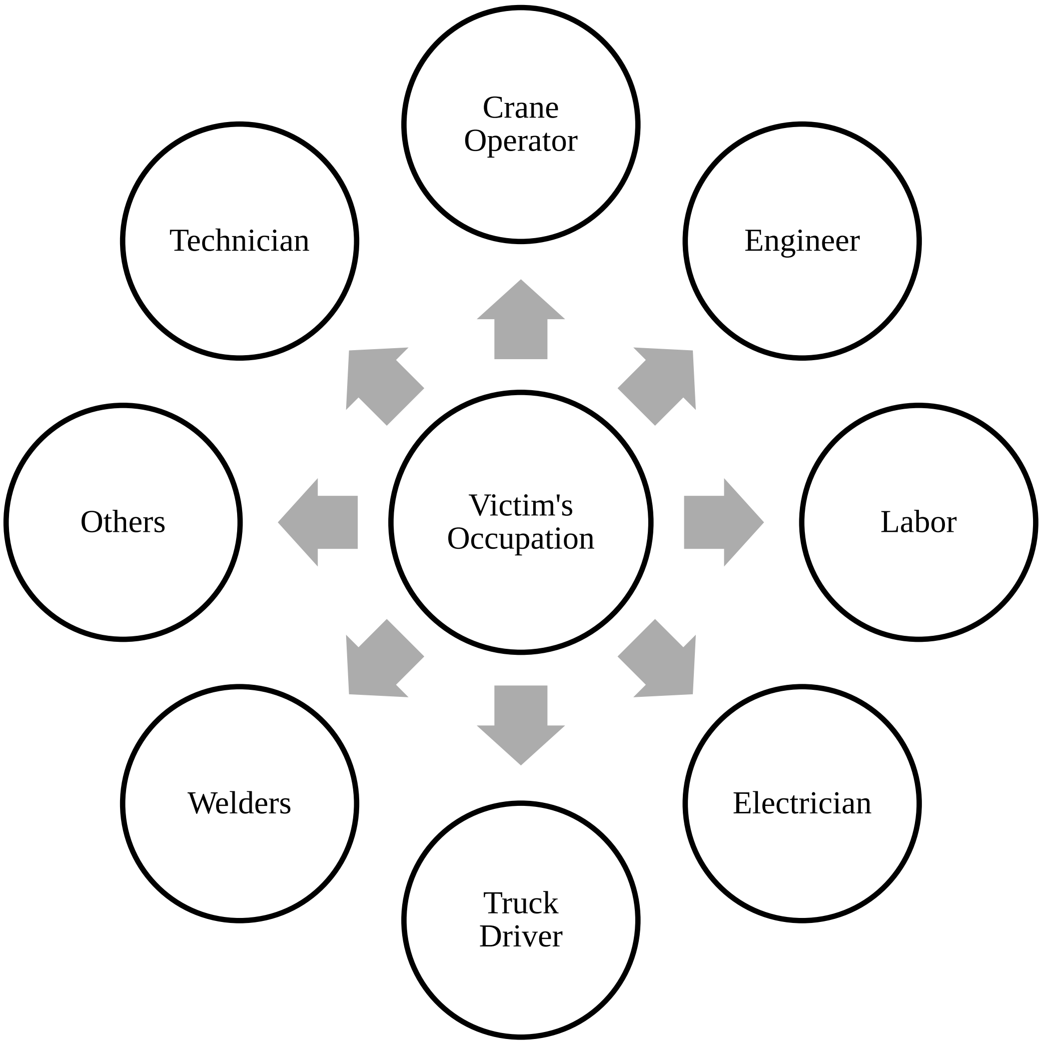

Figure 13 Occupations Affected by Proximal Causes

Analysis of the accidents proves that construction process in one way or another is the reason of a crane mishap. But there are always contributing factors which increase the probability. Following table shows the co-relation between accident types and contributing factors.

Table 8 Matrix of Proximal cause with Contributing Factors

Proximal Cause	Contributing Factors
Crane Tip Over	Outrigger Failure Side Pull Improper assembly Improper operation Wind
Struck by Load	Outrigger Failure Load Dropped Accelerated Movement Equipment Damage
Crushed during Assembly/Disassembly	Improper assembly Improper disassembly-pin support
Struck by Crane parts	Inattention Intentional turntable turning
Failure of Cable	Improper assembly Cable Snap Overload
Failure of Boom	Improper assembly Cable Snap Overload Boom Buckling Two blocking
Electrocution	Failure to maintain required distance Improper Communication Improper Operation
Fall	Improper operation Improper Communication

Contributing factors mentioned in Table-8, were then found to be related with the construction operations as shown in Figure 13. CIRPC had developed a coded list of construction operations (Schriver & and Cressler, 2002) that was recently updated to include cleanup, electrical distribution and transmission, maintenance, and mobilization. This list was further refined to 12 types so that some significance can be achieved in determining the probability as shown in Figure 14.

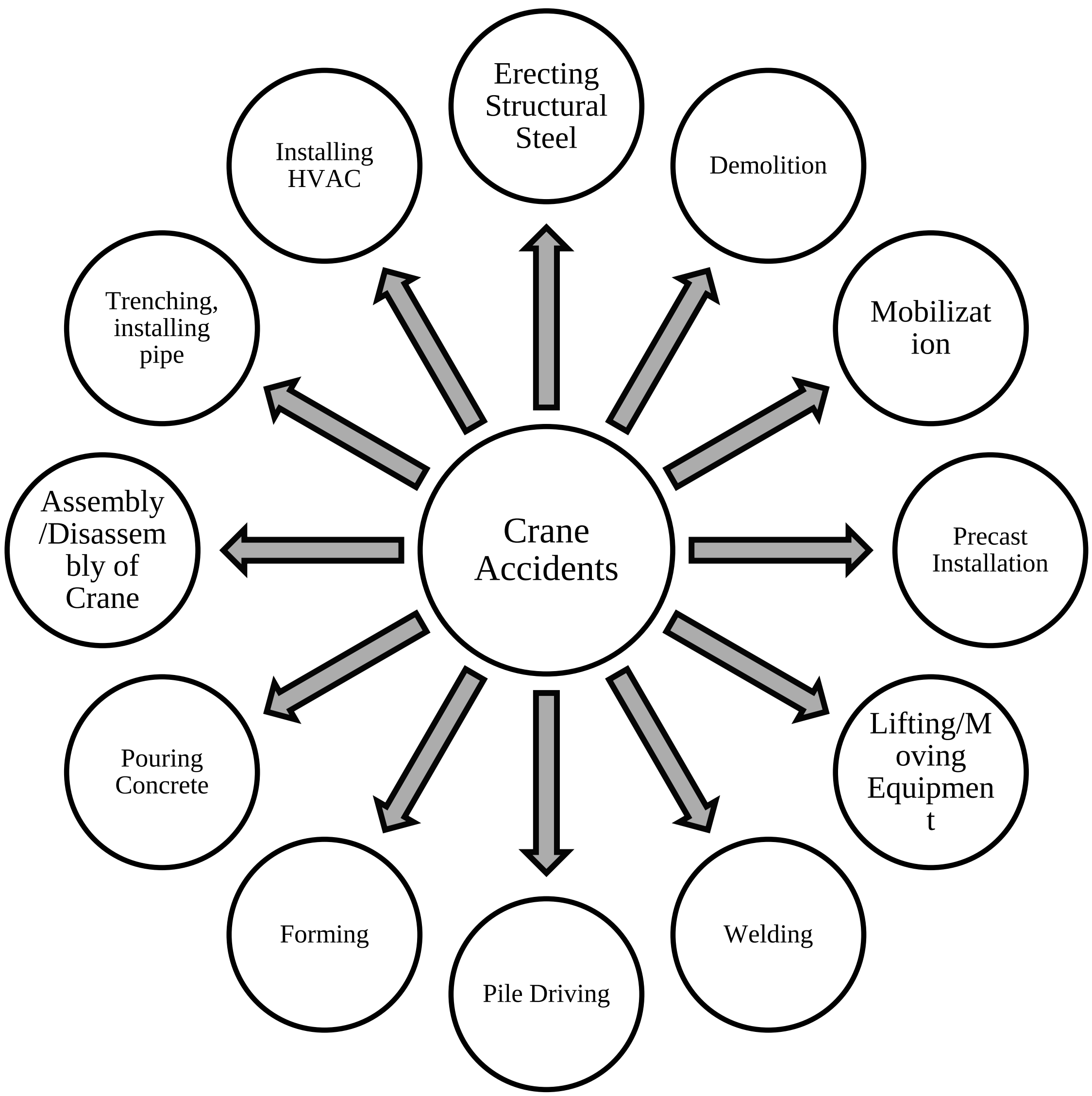

Figure 14 Matrix of Construction Operations Identified from Crane Accident Inspections

3.3.1 Findings

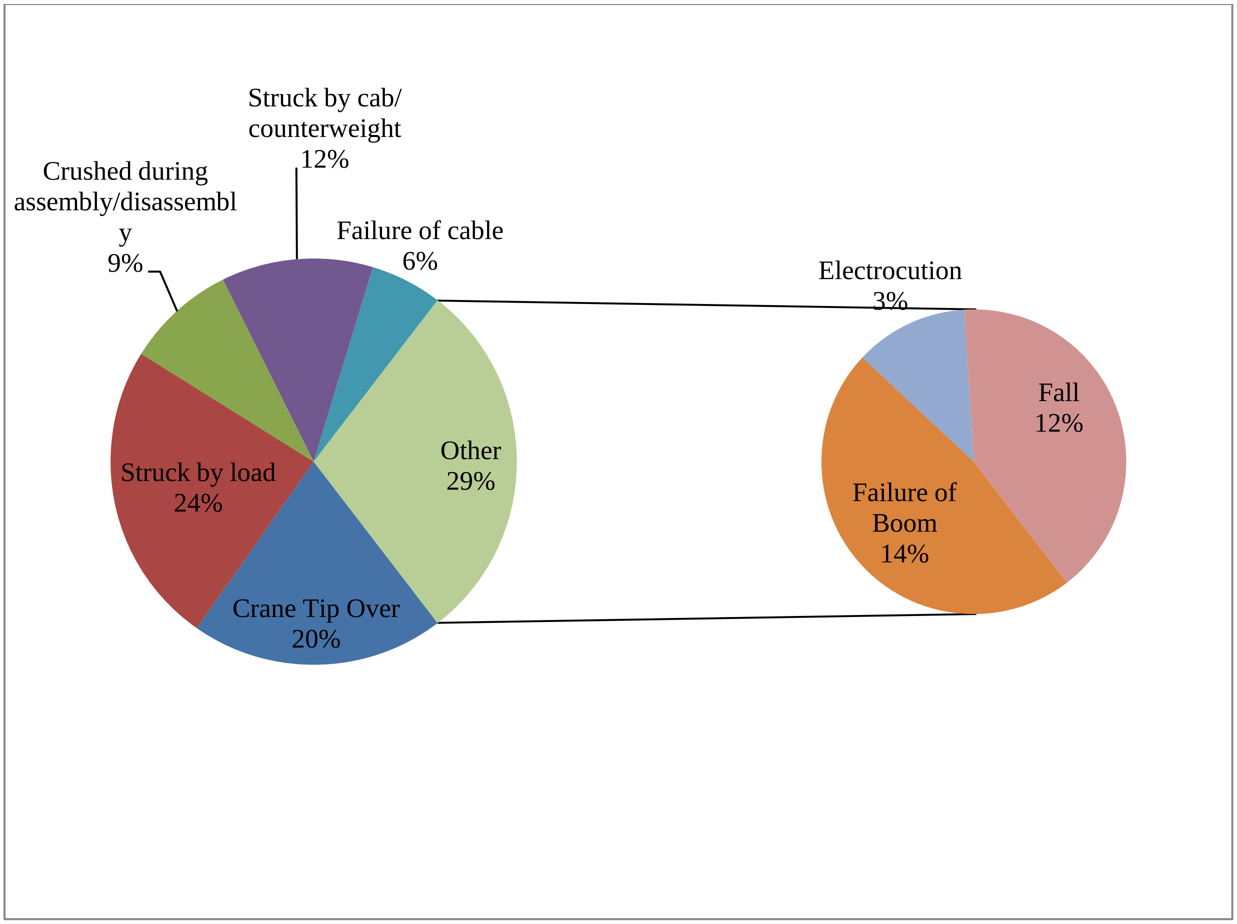

Figure 15 Descriptive of Types of Accident

Figure 15 shows the percentages of different types of accidents. Struck by load was the accident with most number of cases followed closely by crane tip over. These percentages comprise both fatal and non-fatal accidents.

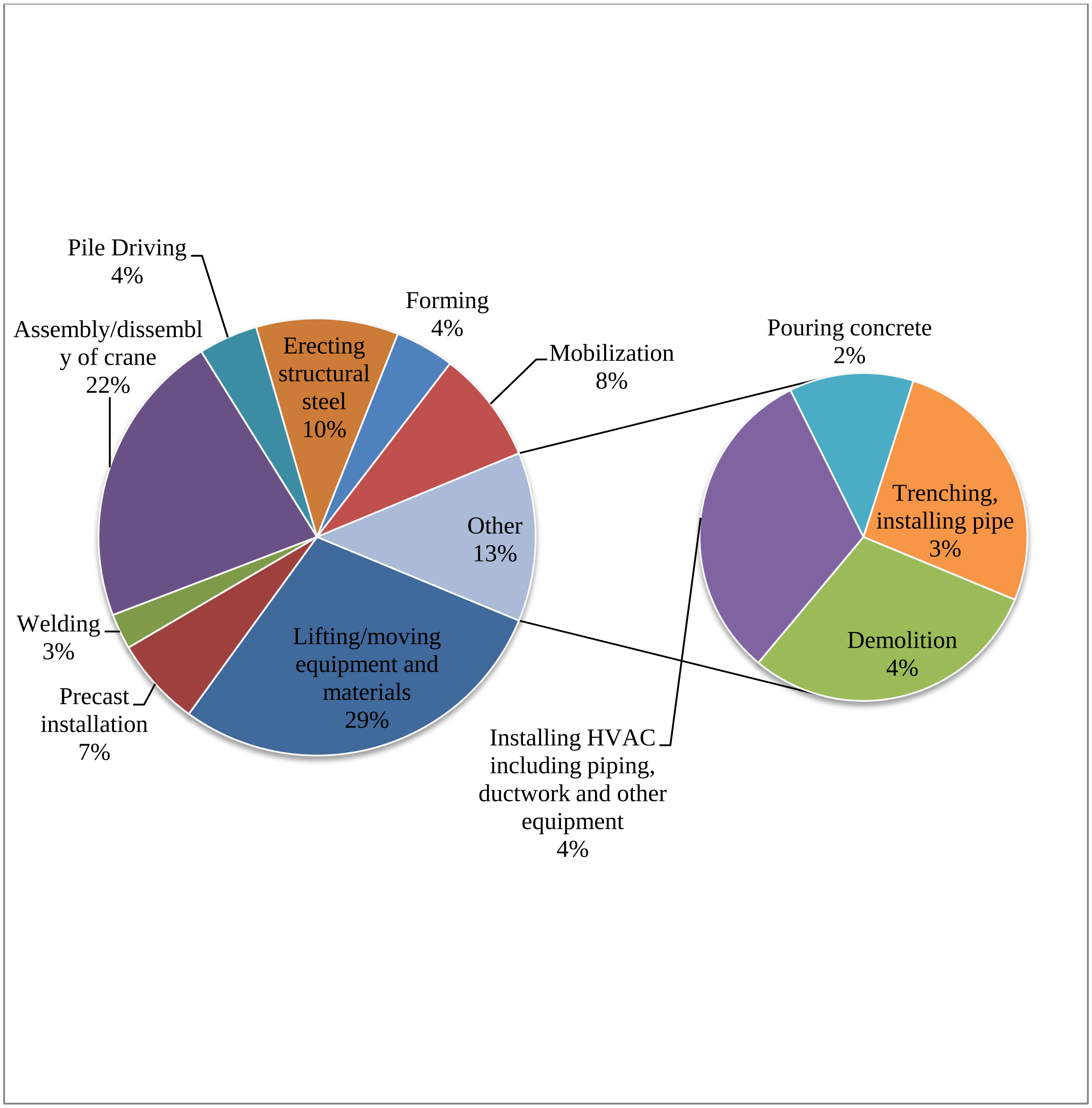

Figure 16 Pie Chart of Construction Operation Percentages in Co-relation to Accidents

Figure 16 shows the percentages of accident happening during various construction operations.

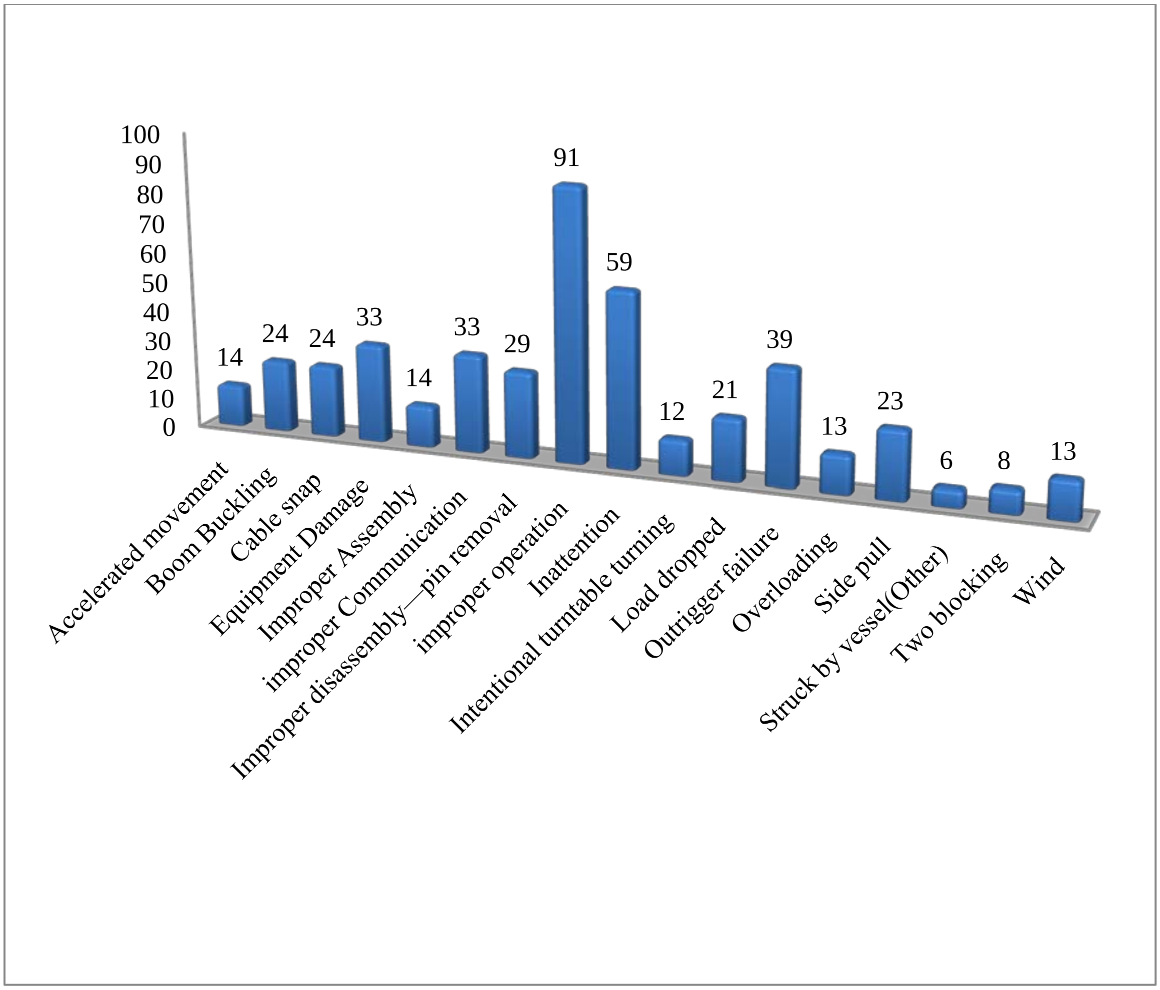

Figure 17 Bar Graph for Contributing Factors to Accidents

Figure 17 shows the frequency of contributing factors which lead to different types of accidents.

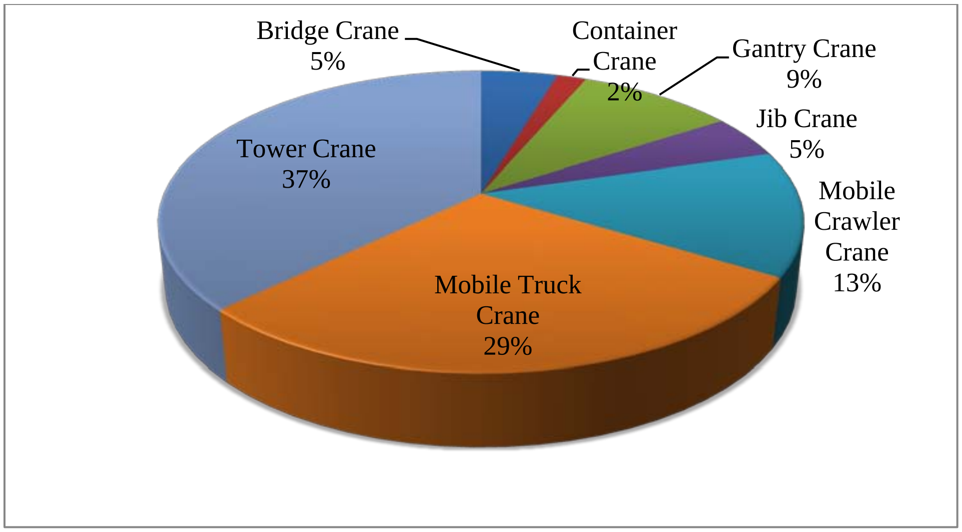

Figure 18 Percentages of Different Types of Cranes Involved in Accidents

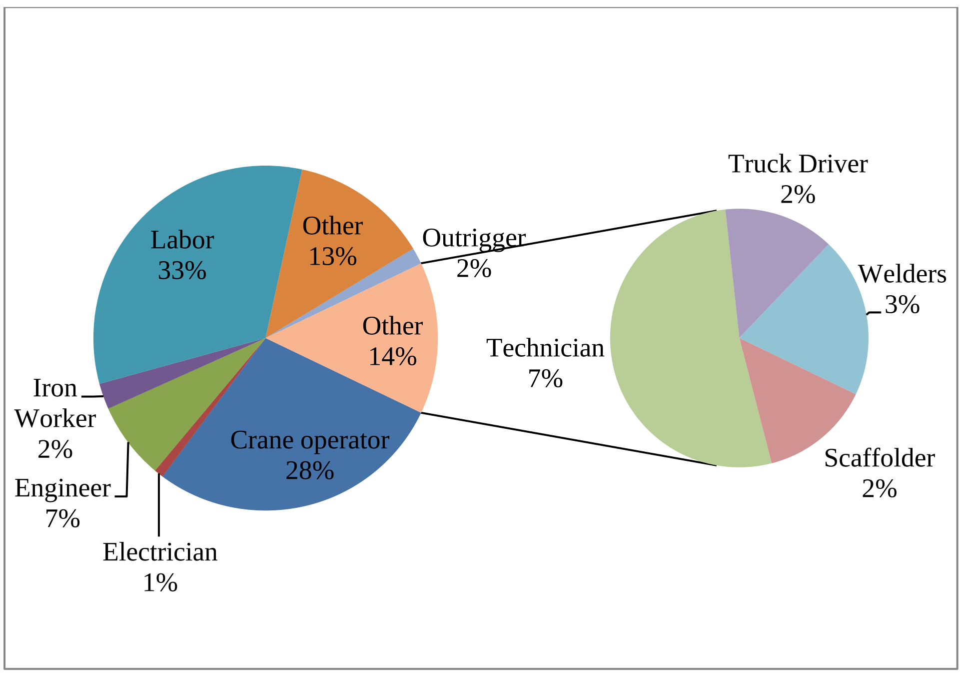

Figure 19 Occupations of the Victims Affected

Figures 18 and 19 show the percentages of different types of cranes and the professionals involved in different types of accidents respectively.

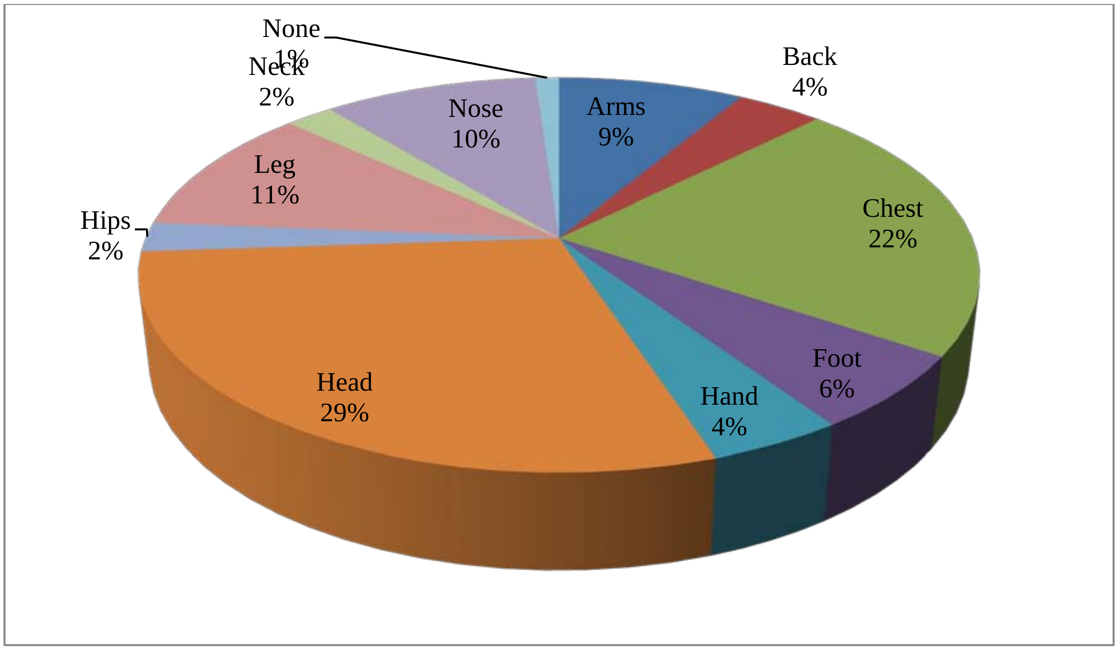

Figure 20 Organs Affected During Crane Accidents

Figure 20 shows the percentages of different body organs hurt during crane accidents.

3.4 Summary

Crane accidents that have happened during 2000 to 2006 were searched on U.S. Department of Labor statistics (OSHA, Crane Accidents, 2010). 672 accidents have been identified during that time frame and all the accident inspections provided by OSHA have been analyzed with respect to various variables that are important while predicting the probability of a crane accident happening in future. Variables identified are construction Operation, Contributing factors, Victim's Occupation, Type of Crane, Load, fault and degree of the accident.

This research compliments the previous studies in the analyses and the methodology, which is similar to the keywords mentioned by OSHA to identify various types of crane accidents. The only difference in descriptive analyses is the inclusion of both fatal as well non-fatal accidents in this research. 8 types of crane accidents or proximal causes were identified and struck by load was identified as the most prominent accident followed by crane tip over. Although electrocution have been identified as the biggest threat in previous studies which analyzed the data from 1990s to 2000. Data analyses from 2000 to 2006 show that the trend is not same anymore and if we consider both fatal and non-fatal percentage goes down even more.

Similar to previous studies, this research shows that rather than crane operator it is the labor which is most affected by crane accidents. There are big percentages of people mentioned in category ‘Other’ which accounts for occupation either not related to construction or occupation numbers insignificant as compared to rest of the occupations mentioned.

Tower crane had most number of accidents reported, which was nearly matched by mobile truck cranes. Primary function of cranes is to lift or move the material, but surprisingly; lifting is responsible for approximately one-fourth accidents only. Analyses shows assembly or disassembly of the cranes is a key factor in crane accidents followed by erecting structural steel and precast installation. Contributing to these operations, improper operation was the primary reason for most of the accidents where fault was manual while outrigger failure was the main contributing factor for accidents when the fault was technical.

From the extensive literature review for this research, it was observed that none of the studies show the victim’s organs affected in accident. Extra precautionary measures can be of great help, if the most significant organ affected is know and the research shows head and chest are two organs which are most affected.

3.5 Why Logit Modeling

The main objective of this research is determining the significance of different factors involved in a crane accident. Logit modeling offers the best option available to find correlation with so many variables involved in crane accidents. Logit modeling part of the domain of multinomial logit modeling starts with foundation as simple regression analysis. According to Menard “The development and explanation of logistic regression from the perspective of linear regression is the movement, step by step, from predicting a dichotomous outcome, which may be expressed as a probability, to a continuous outcome with no upper or lower limit, the natural logarithm of the ratio of one probability to another related probability.” (Menard, 2009)

“Simple regression is applied when there is one nominal variable with two values (dead/alive, manual/technical, etc) and one measurement variable” (Hosmer & Lemeshow, 2000). The nominal variable is the dependent variable, and the measurement variable is the independent variable.

Logit Modeling is used when the dependent variable is nominal and there is more than one independent variable. It is analogous to multiple linear regressions, and all of the same caveats apply (Hosmer & Lemeshow, 2000; Menard, 2009).

Simple logistic regression is analogous to linear regression, except that the dependent variable is nominal, not a measurement. One goal is to see whether the probability of getting a particular value of the nominal variable is associated with the measurement variable; the other goal is to predict the probability of getting a particular value of the nominal variable, given the measurement variable.

One peculiar characteristics of the crane accident data that we have is that a given set of values for the different factors (example location, time, crane type) can lead to more than one kind of accidents. However, the probability of occurrence of one kind of accident can be different from the other kinds. When the data behaves as above, the logit modeling is the best possible option available (Menard, 2009).

4. METHODOLOGY

4.1 Data Collection

All the data was collected from U.S. Department of Labor Statistics (OSHA, Crane Accidents, 2010) sorted by years. Excel was then used as database software in which all the variables were transformed to nominal data which could then be understood by SPSS. Data was collected in December 2009 and OSHA had published the crane accident inspections only till 2006.

4.2 Coding and Output

All the data was then analyzed in SPSS. Before the data was analyzed in SPSS, each variable was coded in a nominal format. Table 9 shows the coding for contributing factors in crane accidents.

Table 9 Statistical Coding Format

Code	**Contributing Factors**	**Accident type**	**Construction Operation**	**Crane type**	**Victim's Occupation**
1	Accelerated movement	Crane Tip Over	Assembly/ disassembly of crane	Bridge Crane	Crane operator
2	Boom Buckling	Struck by load	Demolition	Container Crane	Electrician

Table 9 Continued

Code	Contributing Factors	Accident type	Construction Operation	Crane type	Victim's Occupation
3	Cable snap	Crushed during assembly/ disassembly	Erecting structural steel	Gantry Crane	Engineer
4	Equipment Damage	Struck by crane parts	Forming	Jib Crane	Iron Worker
5	Improper Assembly	Failure of Cable	Installing HVAC	Mobile Crawler Crane	Labor
6	improper Communication	Failure of Boom	Lifting/moving equipment and material	Mobile Truck Crane	Others
7	Improper disassembly—pin removal	Electrocution	Mobilization	Tower Crane	Technician
8	improper operation	Fall	Pile Driving		Truck Driver
9	Inattention		Pouring concrete		Welder
10	Intentional turntable turning		Precast installation		
11	Load dropped		Trenching, installing pipe		
12	Outrigger failure		Welding		
13	Overloading				
14	Side pull				

Table 9 Continued

Code	Contributing Factors	Accident type	Construction Operation	Crane type	Victim's Occupation
15	Struck by vessel(Other)				
16	Two blocking				
17	Wind				

Code is simply a numerical value assigned to all the variables for Statistical software to analyze. After importing the data to SPSS descriptive analysis was done on all the variables, findings of this procedure were shown in Section 3.3.1. This analysis compliments the previous studies where they have been statistically analyzed exclusively.

Another analysis was performed to find the correlation between construction operations, accident type, contributing factors and crane types with the load. Figure 21 scatter plot shows the co relation which gives a visual idea of where the probability of accident happening might be more.

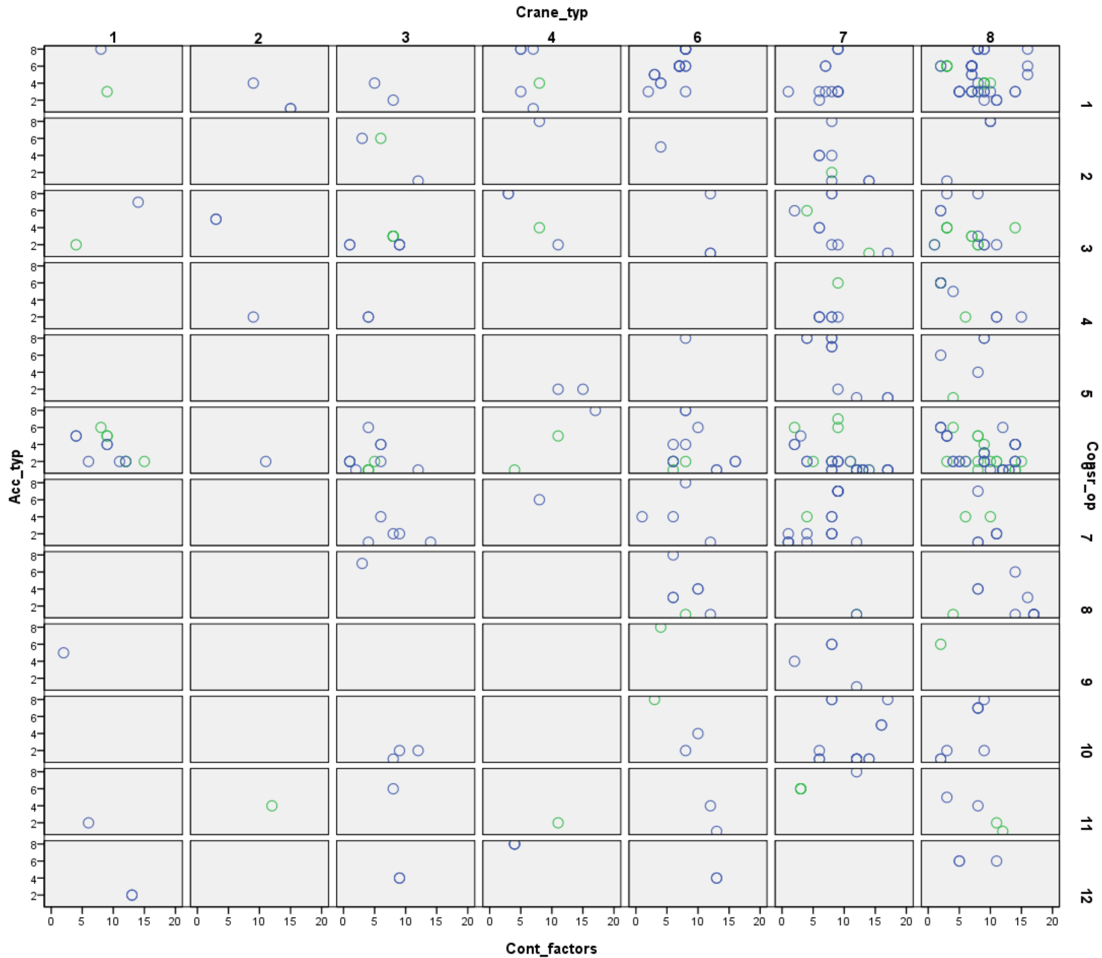

Figure 21 Scatter Plot showing Correlations for Crane type, Accident type, Construction Operation and Contributing factors with respect to Load

4.3 Logit Modeling

In applying an unordered probability model to assess crane accidents, we begin by defining a linear function that determines probability of occurrence of accident as,

$S_{in} = \beta_i X_{in} + \varepsilon_{in}$ (Shankar & Mannering, 1996) (1)

where X_{in} is a vector of measurable characteristics (contributing factor, Proximal cause, and so on) that determines the occurrence of accident n, β_i a vector of estimable coefficients, and ε_{in} is an error term accounting for unobserved effects influencing the crane accident 'n'. McFadden (1981) has shown that if ε_{in} are assumed to be generalized extreme value distributed the standard multinomial Logit model results.

$$P_n(i) = \frac{\exp[\beta_i X_{in}]}{\sum \exp\,[\beta_I X_{In}]} \quad \text{(Shankar \& Mannering, 1996)} \qquad (2)$$

where $P_n(i)$ is the probability of contributing factor 'n' which will result in accident 'i' and I is the set of variables involved in crane accidents. Eq. (2) is estimable by standard maximum likelihood techniques. The generalized extreme value distribution can also be used to generate a family of models that includes the nested Logit model (McFadden, 1981), which can overcome the restriction of the standard multinomial Logit model that requires the assumption that the error terms (ε_{in}'s) are independently distributed across alternate outcomes This independence may not always be the case if some accidents share unobserved effects. For example, with the eight accident categories that will be considered (Struck by load (other than failure of boom/cable), Electrocution, Crushed during assembly/disassembly, Failure of boom, Failure of cable, Crane tip over, Struck by crane parts, Falls), it is possible that no accident may share observed effects that relate to listed contributing factors, thus violating the assumption that the error terms are independently distributed across outcomes. The nested Logit model resolves this by grouping alternatives that share unobserved effects into conditional nests (Menard, 2009). The outcome probabilities are determined by differences in the functions determining these probabilities with shared unobserved effects canceling out in each nest. The nested Logit model has the following structure for contributing factors 'n' that result in crane accident 'i'.

$$Pn(i) = \exp[\beta iXin + \emptyset LSin] \Big/ \sum \exp[\beta I \mathrm{XIn} + \emptyset LSIn] \tag{3}$$

$$Pn(j|i) = \exp[\beta iXin] \Big/ \sum \exp[\beta j|n + XJn] \tag{4}$$

$$Pn(i) = \exp[\beta iXin + \emptyset LSin] \Big/ \sum \exp[\beta I \mathrm{XIn} + \emptyset LSIn] \tag{5}$$

where $P_n(i)$ is the unconditional probability of contributing factor resulting in crane accident outcome '*i*', X's vectors of measurable characteristics that determine the probability of crane accident, β's vectors of estimable coefficients, and Pn(j|i) is the probability of 'contributing factor' resulting in proximal cause 'j' conditioned on the crane accident '*i*'. For example, for a nested structure that assumes correlation among construction operation and contributing factor (Lifting/moving the material and overloading) the outcome category '*i*' would be either of seven types of crane accidents and $P_n(j|i)$ would be the binary Logit model of the types of crane accident outcomes. Continuing, J is the conditional set of outcomes (conditioned on *i*), I is the unconditional set of outcome categories (Tip over, Fall, electrocution etc), LS_{in} is the inclusive value (log-sum), and φi is an estimable parameter.

Estimation of a nested model is usually done in a sequential fashion where the procedure is first to estimate the conditional model (Eq. (4)) using only the observations in the sample that are observed having the subset of crash-injury outcomes. Once these estimation results are obtained, the log-sum is calculated (this is the denominator of one or more of the conditional models—see Eq. (5)) for all observations, both those resulting in injury-severity J and those not (for all crashes). Finally, these computed logsums are used as independent variables in the functions as shown in Eq. (3). All this process was be performed in SAS and SPSS software, where the appropriate coding as shown is Section 4.2, is required to get the significant variables as well as probability of accident occurrence.

Figure 22 shows the procedure followed in the research to produce the probability model.

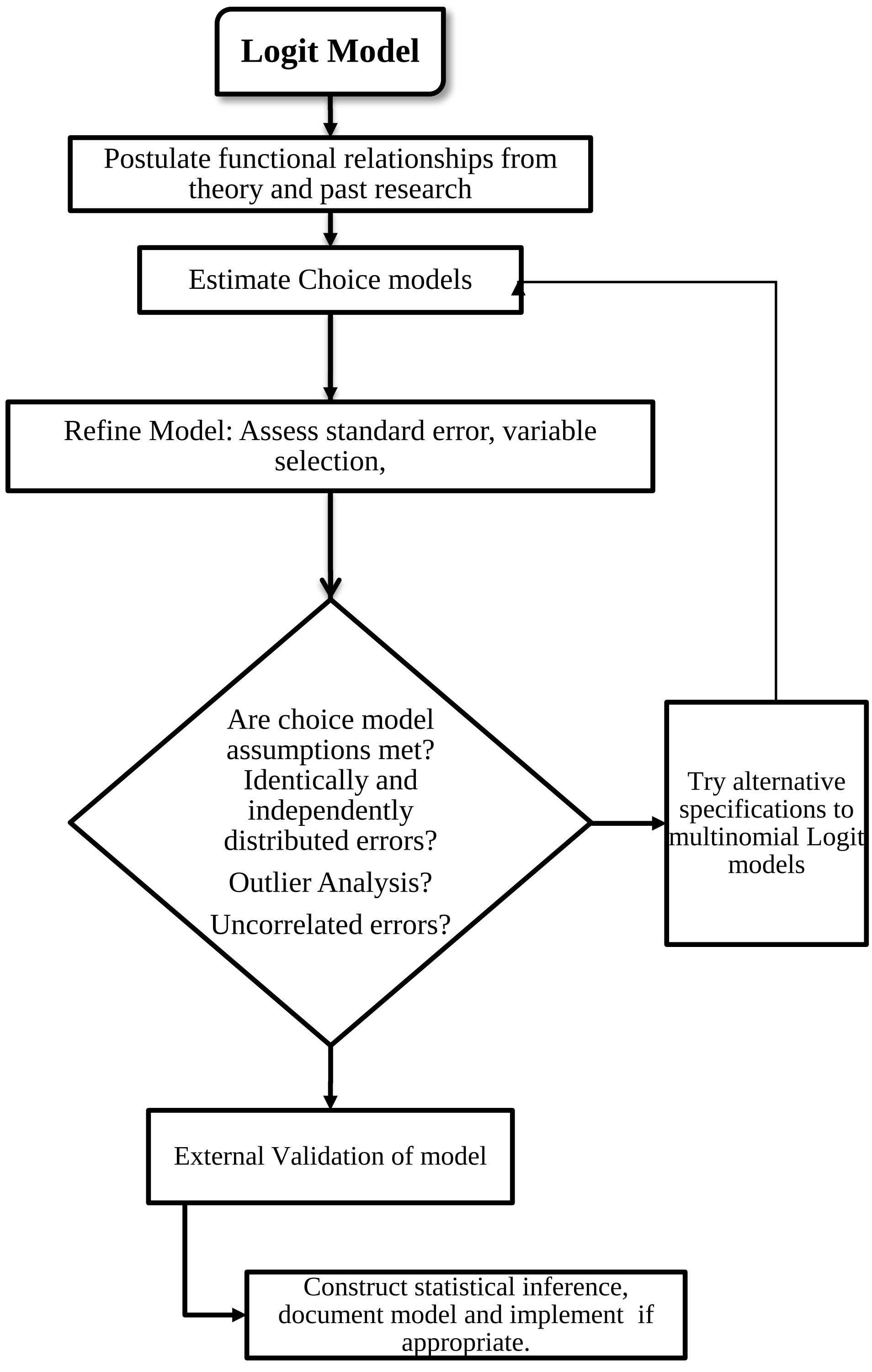

Figure 22 Flowchart for Methodology of Probability Model

4.4 Significance Tests

Significance tests are performed to validate the use of variables in a Logit model. There are several goodness of fit measures available for testing 'how' well a MNL model fits the data on which it was estimated.

The likelihood ratio test is a generic test that can be used to compare models with different levels of complexity. Let L (b¢) be the maximum log likelihood attained with the estimated parameter vector b¢, on which no constraints have been imposed. Let (b¢$_c$) be the maximum log likelihood attained with constraints applied to a subset of coefficients in b¢. Then, asymptotically (i.e. for large samples) -2(L (b¢$_c$)-L (b¢)) has a chi-square distribution with degrees of freedom equaling the number of constrained coefficients. Thus the above statistic, called the "likelihood ratio", can be used to test the null hypothesis that two different models perform approximately the same (in explaining the data). If there is insufficient evidence to support the more complex model, then the simpler model is preferred. For large differences in log likelihood there is evidence to support preferring the more complex model to the simpler one.

In the context of discrete choice analysis, two standard tests are often provided. The first test compares a model estimated with all variables suspected of influencing the choice process to a model that has no coefficients whatsoever—a model that predicts equal probability for all choices.

For this research Log likelihood table, p-value, wald statistic and Standard error have been used to identify the correct variables for the model of that particular accident.

5. RESULTS

This section discusses the models derived via logit modeling. The following findings focus on the qualitative interpretation of the models formed. The section will start with discussion on the validity of the models and the significance tests. This is first step which is applied to check the variables selected are good or do we need to change the variables if they are not significant.

5.1 Significance Tests

As discussed in Section 2, a common use of the likelihood ratio test is to test the difference between a full model and a reduced model dropping an interaction effect. If model chi-square (which is -2LL for the full model minus -2LL for the reduced model) is significant, then the interaction effect is contributing significantly to the full model and should be retained.

Tables 10-17 provide the model fitting information for all the accident types which will lead to the actual formation of probability model. The log likelihood starts with the null hypothesis that all the coefficients have a zero value and they are not significant, the value for that model is provided by intercept only. The second column shows the value of the model with all variables. Chi-Square test is then performed on these values which gives us the p-value. If the p-value <=.05 null hypothesis is rejected and it implies the selected model has the variables which are significant. There is a column for degrees of freedom, which are the number of free variables in a set of observations used to estimate statistical parameters. For instance, the estimation of the population standard deviation computed on a sample of observations requires an estimate of the population mean, which consumes one degree of freedom to estimate-thus the sample standard deviation has n-1 degrees of freedom remaining. The degrees of freedom associated with the error around a linear regression function have n-2 degrees of freedom, since two degrees of freedom have been used to estimate the slope and intercept of the regression line.

Table 10 Model Fitting Information (Crane Tip Over)

	Model Fitting Criteria	Likelihood Ratio Tests		
Model	-2 Log Likelihood	Chi-Square	df	p-value
Intercept Only	420.539			
Final	163.662	256.877	35	.000

Table 11 Model Fitting Information (Struck by Load)

	Model Fitting Criteria	Likelihood Ratio Tests		
Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	493.485			
Final	275.268	218.217	38	.000

Table 12 Model Fitting Information (Crushed during Assembly/Disassembly)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	220.264			
Final	119.912	100.352	30	.000

Table 13 Model Fitting Information (Struck by crane parts)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	322.951			
Final	242.020	80.932	38	.000

Table 14 Model Fitting Information (Failure of Cable)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	171.325			
Final	62.956	108.369	32	.000

Table 15 Model Fitting Information (Failure of Boom)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	308.253			
Final	165.946	142.306	31	.000

Table 16 Model Fitting Information (Electrocution)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	171.325			
Final	62.956	108.369	32	.000

Table 17 Model Fitting Information (Fall)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	304.687			
Final	173.715	130.972	35	.000

After analyzing the values from tables 10-17, null hypothesis has been rejected for all the accident types and Log likelihood tables shows that all the models are appropriate for finding probability of accident occurrence.

Next step is to check the significance of individual variable in that model, which are also tested by log likelihood. Tables 18- 25 provide the significance values for all the variables while they will be discussed in detail under Section 5.2.

Table 18 Likelihood Ratio Test (Crane Tip Over)

	Model Fitting Criteria	Likelihood Ratio Tests		
Effect	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	163.662	0		.
fatal	163.765	.103	1	.748
fault	163.877	.215	1	.643
cons_op	196.112	32.450	8	.000
cont_fact	313.079	149.417	14	9.402E-25
occup	180.782	17.120	6	.009
load	170.675	7.013	1	.008
crane_type	168.822	5.160	4	.271

Table 19 Likelihood Ratio Test (Struck by Load)

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	275.268	0.000E+00		.
fatal	275.616	.348	1	.555
fault	285.951	10.683	1	.001
cons_op	335.753	60.485	10	2.934E-09
cont_fact	394.851	119.583	14	7.594E-19
occup	286.568	11.299	6	.080
load	276.510	1.242	1	.265
crane_type	285.258	9.990	5	.076

Table 20 Likelihood Ratio Test (Crushed during Assembly/Disassembly)

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	119.912	0		.
fatal	120.151	.239	1	.625
fault	124.304	4.392	1	.036
cons_op	162.046	42.134	7	4.900E-07
cont_fact	136.746	16.834	9	.051
occup	155.582	35.670	6	.000
load	120.097	.185	1	.667
crane_type	134.174	14.262	5	.014

Table 21 Likelihood Ratio Test (Struck by Crane parts)

	Model Fitting Criteria	Likelihood Ratio Tests		
Effect	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	242.020	0.000E+00		.
fatal	242.582	.562	1	.453
fault	245.925	3.905	1	.048
cons_op	256.327	14.307	10	.159
cont_fact	275.561	33.542	14	.002
occup	256.748	14.728	6	.022
load	243.580	1.560	1	.212
crane_type	248.115	6.095	5	.297

Table 22 Likelihood Ratio Test (Failure of Cable)

	Model Fitting Criteria	Likelihood Ratio Tests		
Effect	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	62.956a	.000		.
fatal	66.381	3.425	1	.064
fault	89.028	26.071	1	.000
cons_op	83.850	20.893	8	.007
cont_fact	94.461	31.504	11	.001
occup	70.306	7.350	5	.196
load	63.535	.579	1	.447
crane_type	88.649	25.693	5	.000

Table 23 Likelihood Ratio Test (Failure of Boom)

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	165.946	0.000E+00		.
fatal	168.650	2.703	1	.100
fault	166.098	.151	1	.697
cons_op	172.803	6.857	8	.552
cont_fact	238.585	72.639	12	1.024E-10
occup	168.438	2.491	3	.477
load	175.201	9.254	1	.002
crane_type	170.500	4.553	5	.473

Table 24 Likelihood Ratio Test (Electrocution)

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	27.122a	.000		.
fatal	32.084b	4.962	1	.026
fault	27.142b	.020	1	.887
cons_op	62.470	35.349	7	.000
cont_fact	49.807	22.685	8	.004
occup	36.819	9.697	4	.046
load	34.808b	7.686	1	.006
crane_type	39.417	12.295	5	.031

Table 25 Likelihood Ratio Test (fall)

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	173.715	0.000E+00		.
fatal	174.685	.970	1	.325
fault	173.838	.123	1	.726
cons_op	201.231	27.516	8	.001
cont_fact	209.231	35.516	13	.001
occup	179.858	6.143	6	.407
load	188.772	15.057	1	.000
crane_type	197.412	23.696	5	.000

All the p-values for respective variables provided in Tables 18-25show that variables selected in the models are significant.

5.2 Probability Models

5.2.1 Crane Tip Over

i. Degree of accident: The crane tip over accident has no significant relationship with the degree of accidents (Fatal/non-fatal). However, examining the parameter estimates, the probability of the crane tip over accident is lesser with fatal accident and more with non-fatal.

ii. Fault Type: The accident type is again not significantly dependent on the fault type. From the parameter estimates, the probability of the crane tip over accident increases with the technical fault.

iii. Construction Operation: The accident type- crane tip over is significantly dependent on many construction operation types- 2, 5, 6, 7, 8 and 10. It should be noted that the parameter estimates and their respective significance is given taking the construction operation type- 11 as the reference category. All the construction operation types have positive parameter estimates showing that with each construction operation the probability of the crane tip over accident increases. However, the maximum increase is shown by ‘mobilization’.

iv. Erecting structural steel has insignificant effect on the probability of crane tip over accident.

v. Contributing Factors: Among the different contributing factors- types 1,2,3,4,5,6,8 and 16 have a significant effect on the probability of the crane type accident. Interestingly, all these contributing factors have a negative parameter showing that the probability of this accident type actually decreases with these contributing factors. Inversely, that would mean that the probability of other accident types other than 1 will increase because of these contributing factors.

vi. Occupation of the victim: None of the victim occupation types have a significant effect on the probability of the crane tip over accident. Also, the parameters are negative for all the occupation types. This indicates that other accident types other than the crane tip over will be positively related to the occupation type of the victim.

vii. Load: For a crane tip over accident the load is a crucial element. Also, it has a highly significant relation to the probability of the accident. Looking at the parameter estimates the probability of the crane tip over accident increases with the presence of load. This was also an expected result.

viii. Type of Crane: Surprisingly, none of the crane type has a significant relationship to the probability of the crane tip over accident.

From all the above parameters the probability model equation is as shown below:

$$\log\{\pi\} = \log\{\frac{1-\pi}{\pi}\}$$

$$= 0.317 + [\text{fault}] + [\text{degree}] + [\text{Const}_{\text{Operation}}]$$

$$+ [\text{Contributing}_{\text{factors}}] + [\text{Occupation}] + [\text{Load}] + [\text{Crane type}]$$

where, table 26 provides parameter estimates for crane tip over accident.

Table 26 Parameter Estimates for Accident (Crane tip over)

Crane tip over	Variable Value	Std. Error	p-Value	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
Intercept	.317	2.393	.895		
[fatal=Non-fatality]	-.156	.487	.748	.329	2.2
[fatal=Fatality]	0b	.	.	.	.
[fault=Technical]	.277	.600	.644	.407	4.3
[fault=Manual]	0b	.	.	.	.
[cons_op=Assembly/Disassembly of Crane]	1.263	1.996	.527	.071	176.7
[cons_op=Demolition]	5.127	1.723	.003	5.752	4940.3
[cons_op=Erecting Structural Steel]	1.944	1.572	.216	.321	152.1
[cons_op=Installing HVAC]	4.358	1.817	.016	2.219	2748.0
[cons_op=Lifitng/moving Equipment]	3.906	1.511	.010	2.570	960.1
[cons_op=Mobilization]	5.103	1.639	.002	6.623	4084.1
[cons_op=Pile Driving]	4.639	1.690	.006	3.768	2841.3
[cons_op=Pouring Concrete]	5.511	1.675	.001	9.286	6593.8
[cons_op=Trenching]	0b	.	.	.	.
[cont_fact=Accelerated Movement]	-3.763	1.490	.012	.001	0.4
[cont_fact=Boom Buclikng]	-3.617	1.255	.004	.002	0.3
[cont_fact=Cable Snap]	-4.805	1.592	.003	.000	0.2
[cont_fact=Equipment Damage]	-3.438	1.177	.003	.003	0.3
[cont_fact=Improper Assembly]	-22.113	6966.340	.997	.000	.c
[cont_fact=Improper Communication]	-4.652	1.341	.001	.001	0.1
[cont_fact=Improper disassembly]	-2.698	1.671	.106	.003	1.8
[cont_fact=Improper Operation]	-4.587	1.115	.000	.001	0.1
[cont_fact=Inattention]	-22.322	3778.696	.995	.000	.c
[cont_fact=Turntable turning]	-22.192	6254.492	.997	.000	.c
[cont_fact=Load Dropped]	.835	1.232	.498	.206	25.8
[cont_fact=Outrigger Failure]	21.177	.000	.		1572.0
[cont_fact=Side pull]	-1.451	1.132	.200	.025	2.2

Table 26 Continued.

Crane Tip Over	Variable Value	Std. Error	p-Value	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
[cont_fact=Two Blocking]	-4.971	1.540	.001	.000	0.1
[cont_fact=Wind]	0b	.	.	.	.
[occup=Crane Operator]	-1.187	1.555	.446	.014	6.4
[occup=Engineer]	-.589	1.557	.705	.026	11.7
[occup=Iron Worker]	-2.279	1.963	.246	.002	4.8
[occup=Labor]	-3.047	1.588	.055	.002	1.1
[occup=Others]	-2.433	1.631	.136	.004	2.1
[occup=Technician]	-1.555	2.012	.440	.004	10.9
[occup=Welders]	0b	.	.	.	.
[load=Non-Loaded]	-1.412	.543	.009	.084	0.7
[load=Loaded]	0b	.	.	.	.
[crane_type=Gantry Crane]	.871	.759	.251	.540	10.6
[crane_type=Jib Crane]	1.110	1.210	.359	.283	32.5
[crane_type=Mobile Crawler Crane]	-.114	.786	.885	.191	4.2
[crane_type=Mobile Truck Crane]	1.122	.586	.055	.975	9.7
[crane_type=Tower Crane]	0b	.	.	.	.

a. The reference category is: 0.

b. This parameter is set to zero because it is redundant.

Figure 23 shows the estimated probabilities of crane tip over happening during various construction operations.

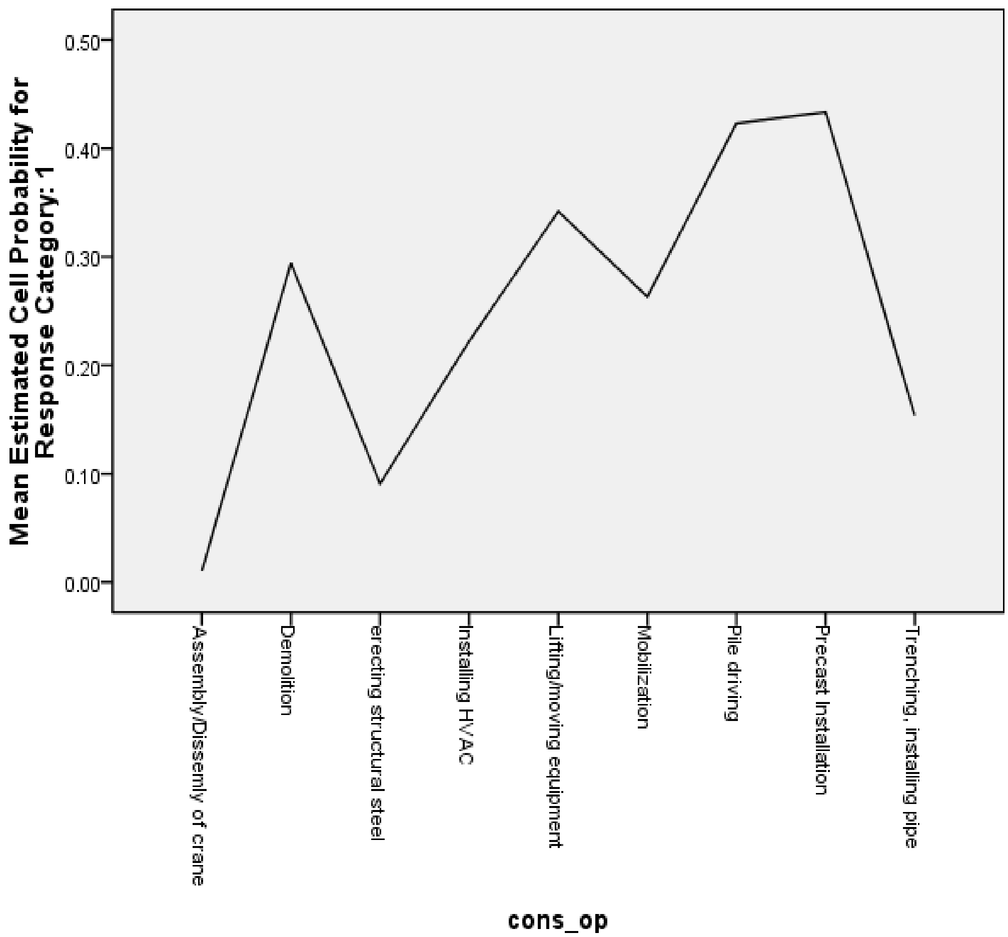

Figure 23 Significance of Construction Operations with respect to Crane Tip Over

5.2.2 Struck by Load

i. Degree of accident: 'Struck by load' has no significant relationship with the degree of accidents (Fatal/non-fatal). However, examining the parameter estimates, the probability of the crane tip over accident is lesser with fatal accident and more with non-fatal.

ii. Fault Type: The accident type is significantly dependent on the fault type. From the parameter estimates, the probability of an accident increases with the technical fault.

iii. Construction Operation: The accident type- struck by load is significantly dependent only on 4. It should be noted that the parameter estimates and their respective significance is given taking the construction operation type- 12 as the reference category. All the construction operation types have positive parameter estimates showing that with each construction operation the probability of the crane tip over accident increases except construction operation 8 which is 'pile driving'. However, the maximum increase is shown by construction operation type -7 which is 'mobilization'.

iv. Contributing Factors: Among the different contributing factors- types 7 and 2 have a significant effect on the probability of the crane type accident. As expected, all these contributing factors have a positive parameter showing that the probability of this accident type increases with these contributing factors. But except accident type 2 and 7 none of the contributing factors are significant. The reference category in this case is 'Wind'.

v. Occupation of the victim: None of the victim occupation types have a significant effect on the probability of the struck by load accident. Also, the parameters are negative for all the occupation types except occupation type 4, 5 and 6.

vi. Load: As expected load is a crucial element. Also, it has a highly significant relation to the probability of the accident

vii. Type of Crane: Surprisingly, none of the crane type has a significant relationship to the probability of the crane tip over accident

From all the above parameters the probability model equation is as shown below:

Logit Model

$$\log\{\frac{1-\pi}{\pi}\} = -23.6 + [\text{fault}] + [\text{degree}] + [\text{Const}_{\text{Operation}}] + [\text{Contributing}_{\text{factors}}] + [\text{Occupation}] + [\text{Load}] + [\text{Crane type}],$$

where, table 27 provides parameter estimates for struck by load accident.

Table 27 Parameter Estimates for Accident (Struck by Load)

Struck by Load	Variable's Value	Std. Error	p-value	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
Intercept	-23.6	1.8	0.0		
[fatal=Non-fatality]	-0.2	0.3	0.6	0.4	1.6
[fatal=Fatality]	0[b]	.	.	.	.
[fault=Technical]	-1.9	0.6	0.0	0.0	0.5
[fault=Non-Technical]	0[b]	.	.	.	.
[cons_op=Assembly/disassembly of crane]	0.3	1.4	0.8	0.1	21.6
[cons_op=Demolition]	0.8	1.7	0.7	0.1	65.0
[cons_op=Forming]	5.2	1.6	0.0	7.8	4504.4
[cons_op=Installing HVAC including piping, ductwork and other equipment]	1.4	1.6	0.4	0.2	92.3
[cons_op=Lifting/moving equipment and materials]	3.1	1.3	0.0	1.6	311.1
[cons_op=Mobilization]	1.6	1.4	0.3	0.3	73.3
[cons_op=Pile Driving]	-16.6	4862.8	1.0	0.0	.[c]
[cons_op=Precast installation]	2.5	1.4	0.1	0.7	200.9
[cons_op=Trenching, installing pipe]	1.8	1.6	0.3	0.3	145.7
[cons_op=Welding]	0[b]	.	.	.	.
[cont_fact=Accelerated movement]	21.9	1.1	0.0	37.5	2.1

Table 27 Continued

Struck by Load	Variable's Value	Std. Error	p-value	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
[cont_fact=Boom Buckling]	0.1	5245.8	1.0	0.0	.[c]
[cont_fact=Erecting structural steel]	19.1	1.1	0.0	20.7	19.3
[cont_fact=Equipment Damage]	20.1	1.0	0.0	80.7	38.2
[cont_fact=Improper Assembly]	20.8	1.2	0.0	17.2	19.3
[cont_fact=improper Communication]	20.5	0.9	0.0	173.0	41.1
[cont_fact=Improper disassembly—pin removal]	1.9	5281.0	1.0	0.0	.[c]
[cont_fact=improper operation]	19.7	0.9	0.0	66.4	13.1
[cont_fact=Inattention]	19.8	0.9	0.0	77.1	27.8
[cont_fact=Load dropped]	25.6	1.5	0.0	75.9	24.6
[cont_fact=Outrigger failure]	18.1	1.0	0.0	95.3	48.0
[cont_fact=Overloading]	18.5	1.2	0.0	13.5	12.9
[cont_fact=Side pull]	17.9	1.2	0.0	56.1	5.3
[cont_fact=Two Blocking"]	20.3	0.0	.	65.4	65.4
[cont_fact=Wind]	0[b]	.	.	.	.
[occup=Crane operator]	0.8	1.1	0.5	0.3	18.7
[occup=Iron Worker]	2.0	1.5	0.2	0.4	131.5
[occup=Labor]	0.8	1.0	0.5	0.3	16.1
[occup=Other]	0.0	1.1	1.0	0.1	8.5
[occup=Technician]	-0.1	1.2	0.9	0.1	10.1
[occup=Welders]	0[b]	.	.	.	.
[load=Non-Loaded]	0.4	0.4	0.3	0.7	3.3
[load=Loaded]	0[b]	.	.	.	.
[crane_type=Bridge Crane]	1.1	0.7	0.1	0.8	12.0
[crane_type=Gantry Crane]	0.4	0.5	0.4	0.6	4.3
[crane_type=Jib Crane]	-2.7	1.6	0.1	0.0	1.6
[crane_type=Mobile Crawler Crane]	-0.5	0.6	0.4	0.2	1.9
[crane_type=Mobile Truck Crane]	-0.2	0.4	0.6	0.3	1.8
[crane_type=Tower Crane]	0[b]	.	.	.	.

a. The reference category is: 0.

b. This parameter is set to zero because it is redundant.

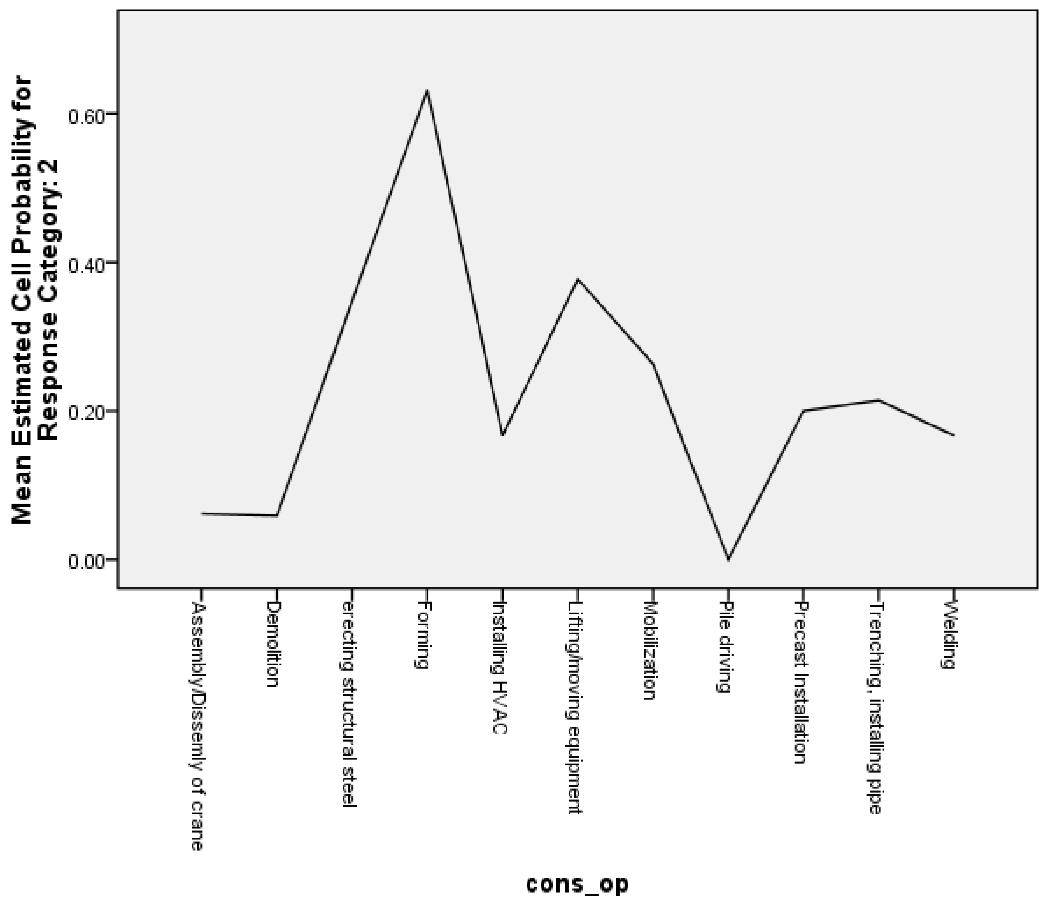

Figure 24 Significance of Construction Operations with respect to Struck by Load

Figure 24 shows the estimated probabilities of struck by load happening during various construction operations.

5.2.3 Crushed during Assembly/disassembly

i. Degree of accident: Fatality is significant in accident type ‘Crushed during assembly/disassembly’ although the significant factor is very small.

ii. Fault Type: The accident type is again not significantly dependent on the fault type. From the parameter estimates, the probability of the ‘crushed during assembly/disassembly’ accident decreases with the technical fault.

iii. Construction Operation: The accident type- crane tip over is significantly dependent on Assembly/disassembly of crane. It should be noted that the parameter estimates and their respective significance is given taking the construction operation type ‘pile driving’ as the reference category. All the construction operation types have negative parameter estimates showing that with each construction operation the probability of the crushed during assembly accident decreases except crushed during assembly/disassembly. However, the maximum decrease is shown by construction operation type ‘mobilization’ which is ‘mobilization’.

iv. Contributing Factors: As Expected, among the different contributing factors- types ‘Improper Assembly’ and ‘Improper disassembly’ have a significant effect on the probability of the ‘Crushed during assembly/disassembly’ crane type accident. Interestingly, all other contributing factors have a negative parameter showing that the probability of this accident type actually decreases with these contributing factors. Inversely, that would mean that the probability of other accident types other than ‘Improper Assembly’ and ‘Improper disassembly' will increase because of these contributing factors.

v. Occupation of the victim: Only 'technician' and 'crane operator' are significantly related to 'Crushed during assembly/disassembly' and they increase the probability of the accident. It is fairly expected result as they are the professionals involved with crane assembly or disassembly. None of the victim occupation types have a significant effect on the probability of the 'Crushed during assembly/disassembly' accident except Iron worker which is negatively related. and the parameters are negative for these occupation types.

vi. Load: Load is not a crucial factor for 'Crushed during assembly/disassembly' accident. This was also an expected result.

vii. Type of Crane: Jib crane and tower crane are significant 'Crushed during assembly/disassembly' accident type, but interestingly Jib crane has negative parameter estimates. Which shows that only 'Tower crane' might have more technical challenges than others.

From all the above parameters the probability model equation is as shown below:

$$\log\{\frac{1-\pi}{\pi}\} = 0.372 + [\text{fault}] + [\text{degree}] + [\text{Const}_{\text{Operation}}] + [\text{Contributing}_{\text{factors}}] + [\text{Occupation}] + [\text{Load}] + [\text{Crane type}]$$

where, table 28 provides parameter estimates for crushed during assembly/disassembly accident.

Table 28 Parameter Estimates for Accident (Crushed During Assembly/Disassembly)

Crushed during assembly/disassembly	Variable Value	Std. Error	p-value	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
Intercept	.372	2.236	.868		
[fatal=Non-fatality]	-.286	.589	.627	.237	2.384
[fatal=Fatality]	0[b]	.	.	.	.
[fault=Technical]	-2.201	1.137	.053	.012	1.029
[fault=Non-Technical]	0[b]	.	.	.	.
[cons_op=Assembly/disassembly of crane]	.582	1.139	.005	.060	5.203
[cons_op=Demolition]	-19.037	9261.380	.998	.000	.[c]
[cons_op=Erecting structural steel]	-1.777	1.340	.185	.012	2.339
[cons_op=Forming]	-19.926	8762.210	.998	.000	.[c]
[cons_op=Installing HVAC including piping, ductwork and other equipment]	-24.009	8470.209	.998	.000	.[c]
[cons_op=Lifting/moving equipment and materials]	-3.805	1.340	.015	.002	.308
[cons_op=Mobilization]	-21.660	5354.733	.997	.000	.[c]
[cont_fact=Accelerated movement]	.275	1.767	.876	.041	42.011
[cont_fact=Boom Buckling]	.766	1.554	.622	.102	45.282
[cont_fact=Improper Assembly]	4.083	1.471	.006	.03	1059.995
[cont_fact=improper Communication]	.242	1.591	.879	.056	28.815
[cont_fact=Improper disassembly—pin removal]	1.245	1.203	.301	.02	36.677
[cont_fact=improper operation]	-.056	1.262	.965	.080	11.210
[cont_fact=Inattention]	1.927	1.310	.141	.527	89.628
[cont_fact=Overloading]	-15.375	.000	.	.000	.000
[cont_fact=Side pull]	.458	1.482	.757	.087	28.879
[cont_fact=16]	0[b]	.	.	.	.
[occup=Crane operator]	-1.639	1.561	.294	.003	4.136
[occup=Engineer]	3.222	1.550	.038	1.201	523.305

Table 28 Continued

Crushed during assembly/disassembly	Variable Value	Std. Error	p-value	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
[occup=Iron Worker]	-18.093	.000	.	.004	.000
[occup=Labor]	-1.810	1.533	.238	.008	3.302
[occup=Other]	-.833	1.492	.577	.023	8.100
[occup=Technician]	.380	1.401	.786	.004	22.798
[occup=Welders]	0^b	.	.	.	.
[load=Non-Loaded]	-.307	.710	.665	.183	2.956
[load=Loaded]	0^b	.	.	.	.
[crane_type=Bridge Crane]	-1.295	1.612	.422	.012	6.455
[crane_type=Gantry Crane]	-1.307	1.112	.240	.031	2.392
[crane_type=Jib Crane]	-4.731	1.663	.004	.000	.229
[crane_type=Mobile Crawler Crane]	-1.769	.931	.057	.028	1.056
[crane_type=Mobile Truck Crane]	.101	.649	.877	.310	3.945
[crane_type=Tower Crane]	0^b	.	.	.	.

Figure 25 shows the estimated probabilities of crushed during assembly/disassembly happening during various construction operations.

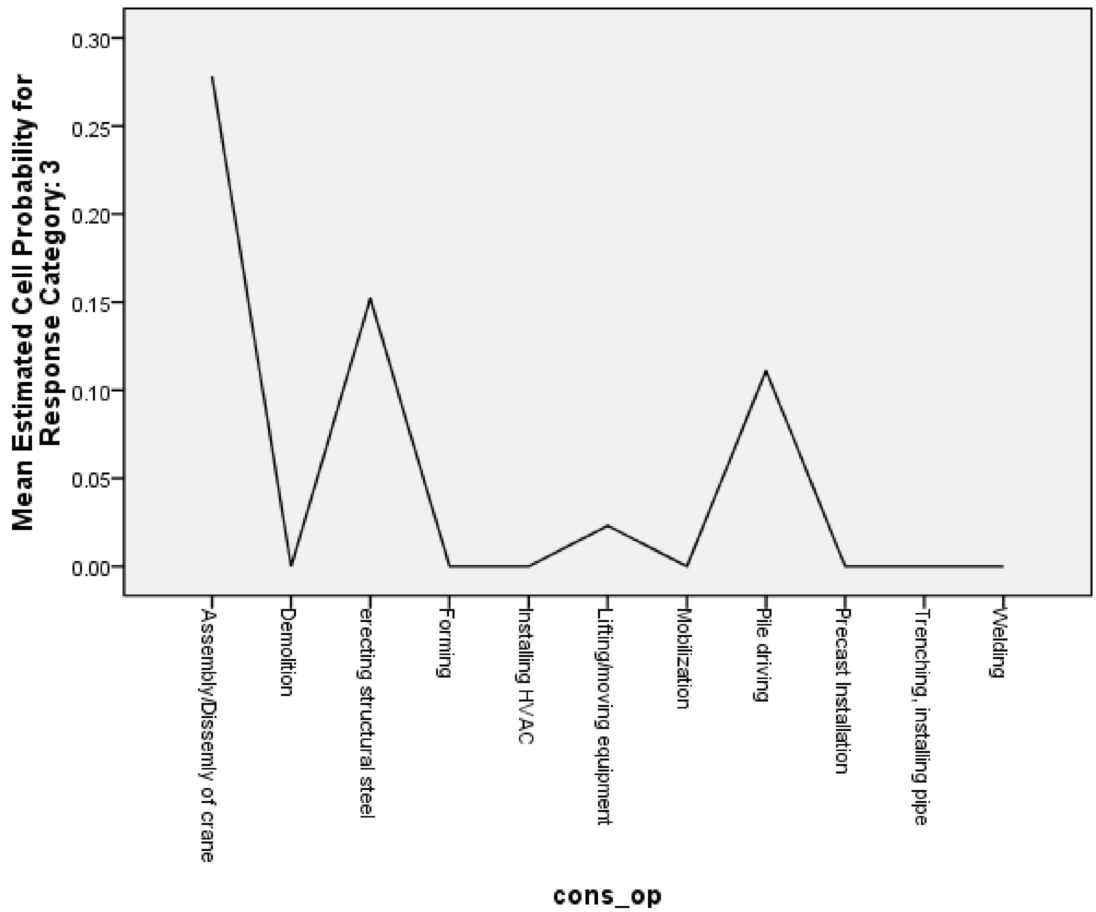

Figure 25 Significance of Construction Operations with respect to Crushed during Assembly/Disassembly

5.2.4 Struck by Crane Parts

i. Degree of accident: The 'Struck by crane parts' accident has no significant relationship with the degree of accidents (Fatal/non-fatal). However, examining the parameter estimates, the probability of the crane tip over accident is lesser with non-fatal accident and more with fatal.

ii. Fault Type: The accident type is again not significantly dependent on the fault type. From the parameter estimates, the probability of the ‘struck by crane parts’ accident decreases with the technical fault.

iii. Construction Operation: Only precast installation is a significant construction operation for accident ‘Struck by Crane parts’. ‘Forming’ cannot be considered because of such a large standard error. All the construction operations are negatively related to ‘struck by load’ accident type. Probability of accident only increases with ‘Trenching, installing pipe’ but it is not significant.

iv. Contributing Factors: Interestingly, except load dropped, and two blocking all other contributing factors are highly significant.

v. Occupation of the victim: Except, ‘Technician’, none of the victim occupation types have a significant effect on the probability of the ‘Struck by crane parts’ accident. Also, the parameters are negative for all the occupation types.

vi. Load: For a ‘Struck by Crane parts’ accident the load is not significant at all. t. Looking at the parameter estimates the probability of the ‘Struck by load’ accident increases with the presence of load. This was also an expected result.

vii. Type of Crane: Surprisingly, none of the crane type has a significant relationship to the probability of the ‘Struck by crane parts’ accident. Which implies each crane is equally susceptible to equipment damage.

From all the above parameters the probability model equation is as shown below:

Logit Model

$$\log\{\frac{1-\pi}{\pi}\} = -16.65 + [\text{fault}] + [\text{degree}] + [\text{Const}_{\text{Operation}}] + [\text{Contributing}_{\text{factors}}] +$$

$$[\text{Occupation}] + [\text{Load}] + [\text{Crane type}],$$

where, table 29 provides parameter estimates for struck by crane parts accidents.

Table 29 Parameter Estimates for Accident type (Struck by Crane parts)

Struck by crane parts	Variable's Value	Std. Error	Sig.	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
Intercept	-16.653	1.352	.000		
[fatal=Non-fatality]	.313	.420	.456	.601	3.114
[fatal=Fatality]	0[b]	.	.	.	.
[fault=Technical]	-1.278	.688	.063	.072	1.073
[fault=Non-Technical]	0[b]	.	.	.	.
[cons_op=Assembly/disassembly of crane]	-.696	1.181	.556	.049	5.049
[cons_op=Demolition]	-.689	1.425	.629	.031	8.202
[cons_op=Erecting structural steel]	-.791	1.148	.491	.048	4.303
[cons_op=Forming]	-18.626	4595.394	.997	.000	.[c]
[cons_op=Lifting/moving equipment and materials]	-1.474	1.157	.203	.024	2.212
[cons_op=Mobilization]	-.119	1.234	.923	.079	9.967
[cons_op=Pile Driving]	-.869	1.321	.511	.031	5.586
[cons_op=Precast installation]	-2.530	1.538	.100	.004	1.624
[cons_op=Trenching, installing pipe]	.034	1.418	.981	.064	16.656
[cons_op=Welding]	0[b]	.	.	.	.
[cont_fact=Accelerated movement]	16.983	1.309	.000	1821.602	3.901E+01
[cont_fact=Boom Buckling]	18.929	.929	.000	2.691E+07	1.027E+09
[cont_fact=Equipment Damage]	17.678	1.030	.000	6318827.270	3.585E+08

Table 29 Continued

Struck by crane parts	Variable's Value	Std. Error	Sig.	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
[cont_fact=improper Communication]	19.097	.807	.000	4.041E+07	9.566E+08
[cont_fact=Improper disassembly—pin removal]	-.688	4201.750	.001	.000	.[c]
[cont_fact=improper operation]	17.746	.756	.000	1.157E+07	2.240E+08
[cont_fact=Inattention]	18.081	.824	.000	1.417E+07	3.580E+08
[cont_fact=Load dropped]	.101	4280.841	1.000	.000	.[c]
[cont_fact=Outrigger failure]	15.814	1.324	.000	550754.669	9.881E+07
[cont_fact=Overloading]	16.938	1.257	.000	1932474.660	2.667E+08
[cont_fact=Wind]	0[b]	.	.	.	.
[occup=Crane operator]	-1.440	.913	.115	.040	1.418
[occup=Engineer]	-2.403	1.049	.022	.012	.707
[occup=Iron Worker]	-1.576	1.148	.170	.022	1.962
[occup=Labor]	-2.156	.881	.014	.021	.651
[occup=Other]	-1.582	.876	.071	.037	1.144
[occup=Technician]	-3.982	1.380	.004	.001	.279
[occup=Welders]	0[b]	.	.	.	.
[load=Non-Loaded]	-.553	.439	.208	.243	1.361
[load=Loaded]	0[b]	.	.	.	.
[crane_type=Bridge Crane]	-.138	.986	.888	.126	6.015
[crane_type=Gantry Crane]	.160	.637	.802	.337	4.089
[crane_type=Jib Crane]	-.626	1.188	.598	.052	5.490
[crane_type=Mobile Crawler Crane]	.899	.570	.114	.805	7.508
[crane_type=Mobile Truck Crane]	-.550	.490	.262	.221	1.509
[crane_type=Tower Crane]	0[b]	.	.	.	.

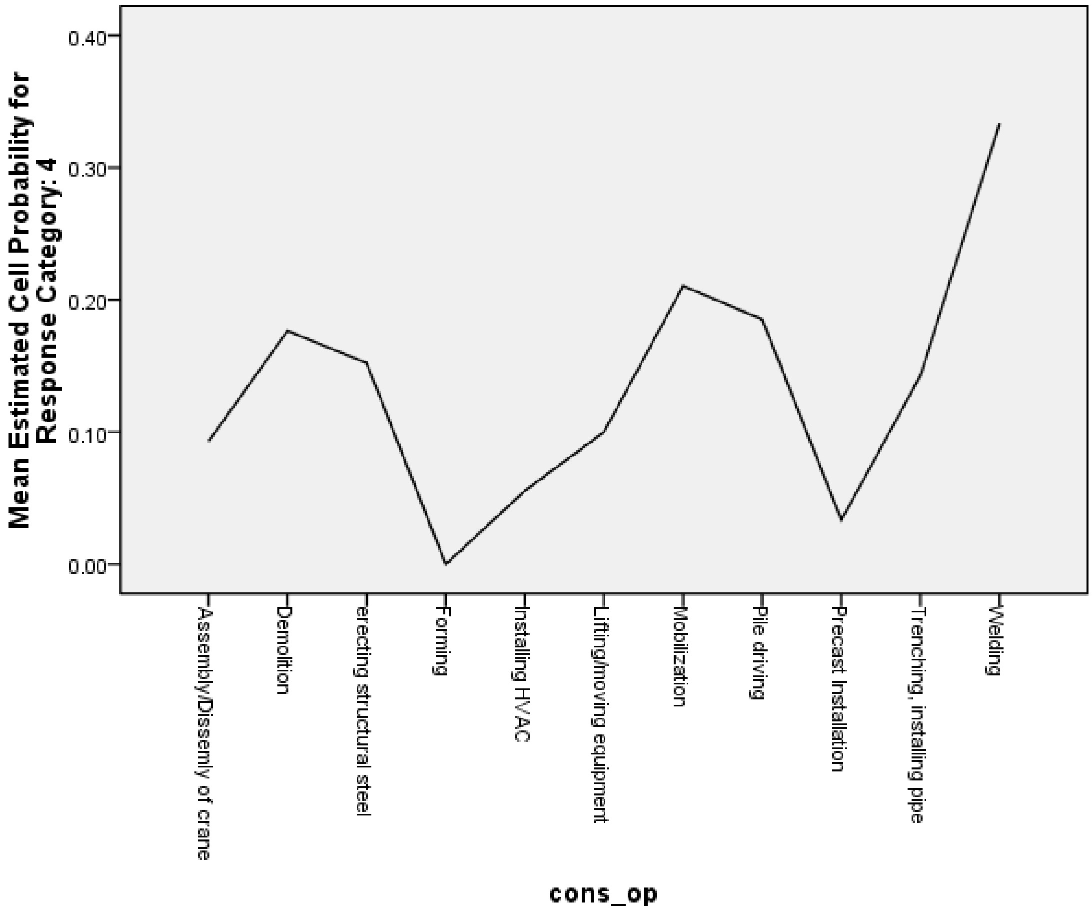

Figure 26 Significance of Construction Operations with respect to Struck by Crane Parts

Figure 26 shows the estimated probabilities of struck by crane parts happening during various construction operations.

5.2.5 Failure of Cable

i. Degree of accident: Failure of cable has no significant relationship with the degree of accidents (Fatal/non-fatal). However, examining the parameter estimates, the probability of the ‘Failure of cable’ accident is lesser with fatal accident and more with non-fatal.

ii. Fault Type: As expected, technical fault is extremely significant as far as failure of cable is concerned and the probability of accident increases drastically.

iii. Construction Operation: Not even a single construction operation was identified as a significant factor. It means cable is as susceptible as in each construction operation. In fact all of them are negatively related to failure of cable. It must be noted that the reference category is precast installation.

iv. Contributing Factors: Among the different contributing factors- types 'Erecting structural steel' has a significant effect on the probability of failure of cable. Interestingly, most of the contributing factors have a negative parameter showing that the probability of this accident type actually decreases with these contributing factors.

v. Occupation of the victim: Failure of cable leads to accidents where all the professional from all occupations are working except 'Iron Worker'

vi. Load: Contrary to the expectation, load is not a significant factor in failure of cable which adds to the conclusion of fault type which is technical and highly significant.

vii. Type of Crane: Mobile crawler crane and gantry crane have been identified as most susceptible to failure of cable.

From all the above parameters the probability model equation is as shown below:

Logit Model

$$\log\{\frac{1-\pi}{\pi}\} = -5.936 + [\text{fault}] + [\text{degree}] + [\text{Const}_{\text{Operation}}] + [\text{Contributing}_{\text{factors}}] + [\text{Occupation}] + [\text{Load}] + [\text{Crane type}],$$

where,

Table 30 Parameter Estimates for Accident Type (Failure of Cable)

Failure of cable	Variable's Value	Std. Error	Sig.	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
Intercept	-5.936	3.1	0.1		
[fatal=Non-fatality]	1.773	1.0	0.1	0.8	45.4
[fatal=Fatality]	0[b]	.	.	.	.
[fault=Technical]	5.263	1.4	0.0	12.2	306.3
[fault=Manual]	0[b]	.	.	.	.
[cons_op=Assembly/disassembly of crane]	-4.011	2.9	0.2	0.0	5.6
[cons_op=Demolition]	-3.354	2.7	0.2	0.0	6.5
[cons_op=Erecting structural steel]	-26.688	9380.4	1.0	0.0	.[c]
[cons_op=Forming]	-3.909	2.7	0.1	0.0	3.9
[cons_op=Installing HVAC including piping, ductwork and other equipment]	-1.983	2.1	0.3	0.0	8.8
[cons_op=Lifting/moving equipment and materials]	-18.517	4958.3	1.0	0.0	.[c]
[cons_op=Mobilization]	-1.899	2.6	0.5	0.0	24.6
[cons_op=Pile Driving]	-2.041	2.4	0.4	0.0	13.3
[cons_op=Precast installation]	0[b]	.	.	.	.
[cons_op=Trenching, installing pipe]	-1.093	1.9	0.6	0.0	14.9
[cont_fact=Erecting structural steel]	3.476	1.5	0.0	1.6	672.3
[cont_fact=Equipment Damage]	.527	1.5	0.7	0.1	33.5
[cont_fact=improper Communication]	-18.374	5606.9	1.0	0.0	.[c]
[cont_fact=Improper disassembly—pin removal]	4.221	2.6	0.1	0.4	156.2
[cont_fact=improper operation]	1.334	1.6	0.4	0.2	82.1
[cont_fact=Inattention]	.641	1.8	0.7	0.1	70.2
[cont_fact=Load dropped]	-1.335	2.1	0.5	0.0	15.0
[cont_fact=Outrigger failure]	-19.109	4106.6	1.0	0.0	.[c]
[cont_fact=Overloading]	-14.371	0.0	.	0.0	0.0
[cont_fact=Side pull]	-16.881	4717.2	1.0	0.0	.[c]

Table 30 Continued

Failure of cable	Variable's Value	Std. Error	Sig.	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
[cont_fact=Two Blocking"]	0[b]	.	.	.	.
[occup=Crane operator]	-1.518	2.7	0.6	0.0	40.6
[occup=Engineer]	2.753	2.5	0.3	0.1	2112.4
[occup=Iron Worker]	-17.505	5574.8	1.0	0.0	.[c]
[occup=Labor]	.918	2.3	0.7	0.0	217.5
[occup=Other]	.372	2.4	0.9	0.0	173.1
[occup=Technician]	0[b]	.	.	.	.
[load=Non-Loaded]	.805	1.1	0.4	0.3	17.8
[load=Loaded]	0[b]	.	.	.	.
[crane_type=Bridge Crane]	5.889	2.0	0.0	7.6	173.1
[crane_type=Gantry Crane]	-19.824	4737.1	1.0	0.0	.[c]
[crane_type=Jib Crane]	1.252	1.7	0.5	0.1	107.6
[crane_type=Mobile Crawler Crane]	-1.230	1.5	0.4	0.0	5.2
[crane_type=Mobile Truck Crane]	-.339	1.2	0.8	0.1	7.1
[crane_type=Tower Crane]	0[b]	.	.	.	.

Figure 27 shows the estimated probabilities of failure of cable happening during various construction operations.

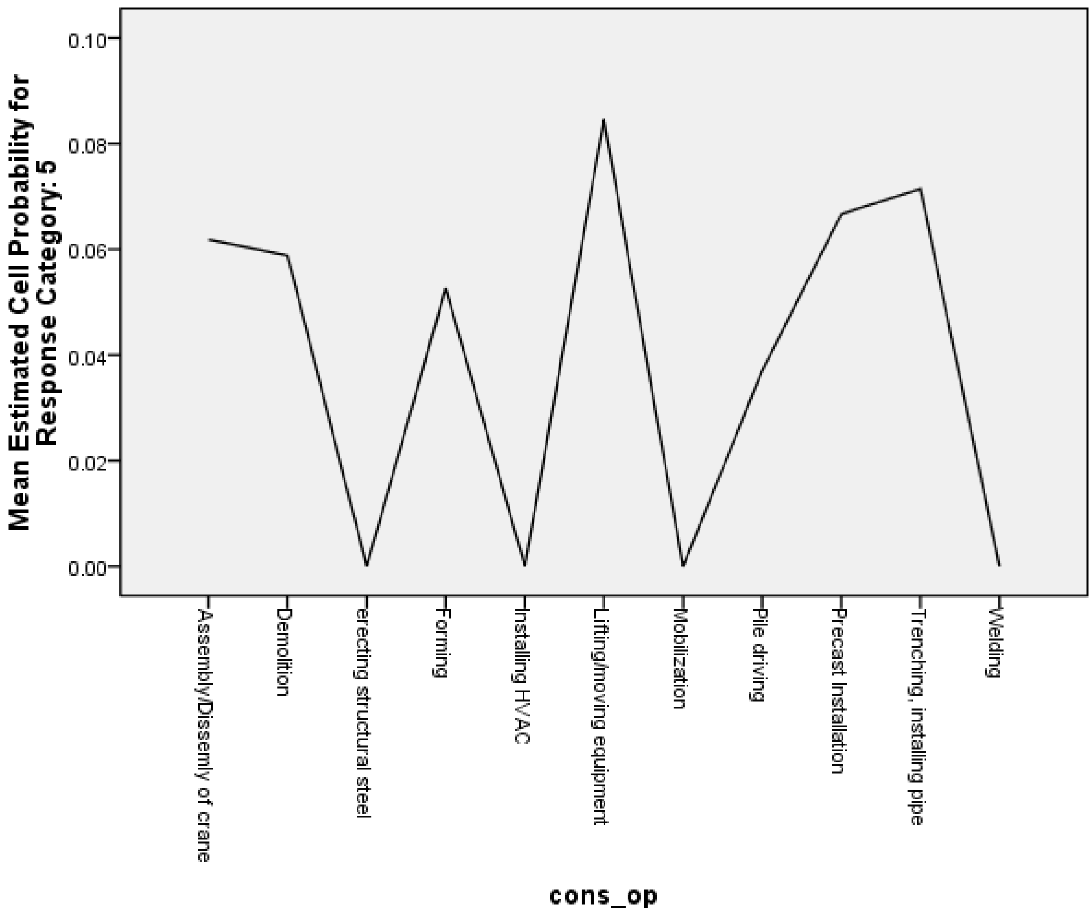

Figure 27 Significance of Construction Operations with respect to Failure of Cable

5.2.6 Failure of Boom

i. Degree of accident: Failure of boom has no significant relationship with the degree of accidents (Fatal/non-fatal). However, examining the parameter estimates, the probability of the crane tip over accident is lesser with non fatal accident and more with fatal.

ii. Fault Type: The accident type is again not significantly dependent on the fault type. From the parameter estimates, the probability of the crane tip over accident increases with the technical fault.

iii. Construction Operation: Failure of boom is not particularly associated with any specific construction operation and the results in Table 15 show that the probability is inversely proportional to the accident type. It .must be noted that 'trenching and installing pipe' is the reference category.

iv. Contributing Factors: Results for contributing factors show interesting trend which are contrary to failure of cable, and all of the contributing factors except improper assembly and load dropped are significant. It should be noted that all of these contributing factors have positive parameters estimates while boom buckling has the maximum parameter estimate, which was expected.

v. Occupation of the victim: None of the victim occupation types have a significant effect on the probability of the crane tip over accident. Although the parameter estimates are positive but their significance is very low.

vi. Load: Again contrary to failure of cable, load is an important factor for failure of boom and is very significant. This implies the load is primarily responsible for boom buckling which is expected.

vii. Type of Crane: Only Tower crane has a significant relationship to the probability of the failure of boom accident.

From all the above parameters the probability model equation is as shown:

Logit Model

$$\log\{\frac{1-\pi}{\pi}\} = -18.4 + [\text{fault}] + [\text{degree}] + [\text{Const}_{\text{Operation}}] + [\text{Contributing}_{\text{factors}}] + [\text{Occupation}] + [\text{Load}] + [\text{Crane type}],$$

where, table 31 provides parameter estimates for failure of boom.

Table 31 Parameter Estimates for Accident type (Failure of Boom)

Failure of Boom	p-value	Std. Error	Sig.	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
Intercept	-18.4	1.8	0.0		
[fatal=Non-fatality]	-0.8	0.5	0.1	0.2	1.2
[fatal=Fatality]	0[b]	.	.	.	.
[fault=Technical]	0.3	0.7	0.7	0.3	4.9
[fault=Non-Technical]	0[b]	.	.	.	.
[cons_op=Assembly/disassembly of crane]	-0.9	1.1	0.4	0.1	3.5
[cons_op=Demolition]	-0.7	1.3	0.6	0.0	6.2
[cons_op=Erecting structural steel]	-1.6	1.2	0.2	0.0	2.0
[cons_op=Forming]	-0.4	1.4	0.8	0.0	9.8
[cons_op=Installing HVAC including piping, ductwork and other equipment]	-1.7	1.6	0.3	0.0	4.3
[cons_op=Lifting/moving equipment and materials]	-1.9	1.1	0.1	0.0	1.2
[cons_op=Mobilization]	-2.0	1.4	0.2	0.0	2.2
[cons_op=Pile Driving]	-1.5	1.2	0.2	0.0	2.5
[cons_op=Trenching, installing pipe]	0[b]	.	.	.	.
[cont_fact=Boom Buckling]	21.0	1.0	0.0	185.0	122.1
[cont_fact=Erecting structural steel]	18.8	1.1	0.0	14.4	11.9
[cont_fact=Equipment Damage]	17.4	1.2	0.0	36.3	37.8
[cont_fact=Improper Assembly]	-1.0	9289.1	1.0	0.0	.[c]
[cont_fact=improper Communication]	15.8	1.5	0.0	32.7	192.0
[cont_fact=Improper disassembly—pin removal]	20.3	1.1	0.0	763.3	526.1
[cont_fact=improper operation]	17.9	1.0	0.0	8.2	41.7
[cont_fact=Inattention]	17.0	1.2	0.0	23.7	29.2
[cont_fact=Load dropped]	-1.0	6340.3	1.0	0.0	.[c]

Table 31 Continued

Failure of Boom	p-value	Std. Error	Sig.	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
[cont_fact=Outrigger failure]	16.7	1.4	0.0	15.6	25.1
[cont_fact=Side pull]	17.6	1.4	0.0	255.6	662.0
[cont_fact=Two Blocking"]	17.8	0.0	.	51.0	51.0
[cont_fact=Wind]	0^b	.	.	.	.
[occup=Crane operator]	0.7	1.2	0.6	0.2	19.5
[occup=Labor]	1.3	1.2	0.3	0.4	39.2
[occup=Other]	1.3	1.2	0.3	0.3	38.5
[occup=Technician]	0^b	.	.	.	.
[load=Non-Loaded]	-1.5	0.5	0.0	0.1	0.6
[load=Loaded]	0^b	.	.	.	.
[crane_type=Bridge Crane]	-0.9	1.3	0.5	0.0	5.6
[crane_type=Gantry Crane]	0.5	0.8	0.6	0.3	8.0
[crane_type=Jib Crane]	-1.0	1.3	0.4	0.0	4.4
[crane_type=Mobile Crawler Crane]	1.1	0.7	0.1	0.8	11.2
[crane_type=Mobile Truck Crane]	0.1	0.5	0.9	0.4	3.2
[crane_type=Tower Crane]	0^b	.	.	.	.

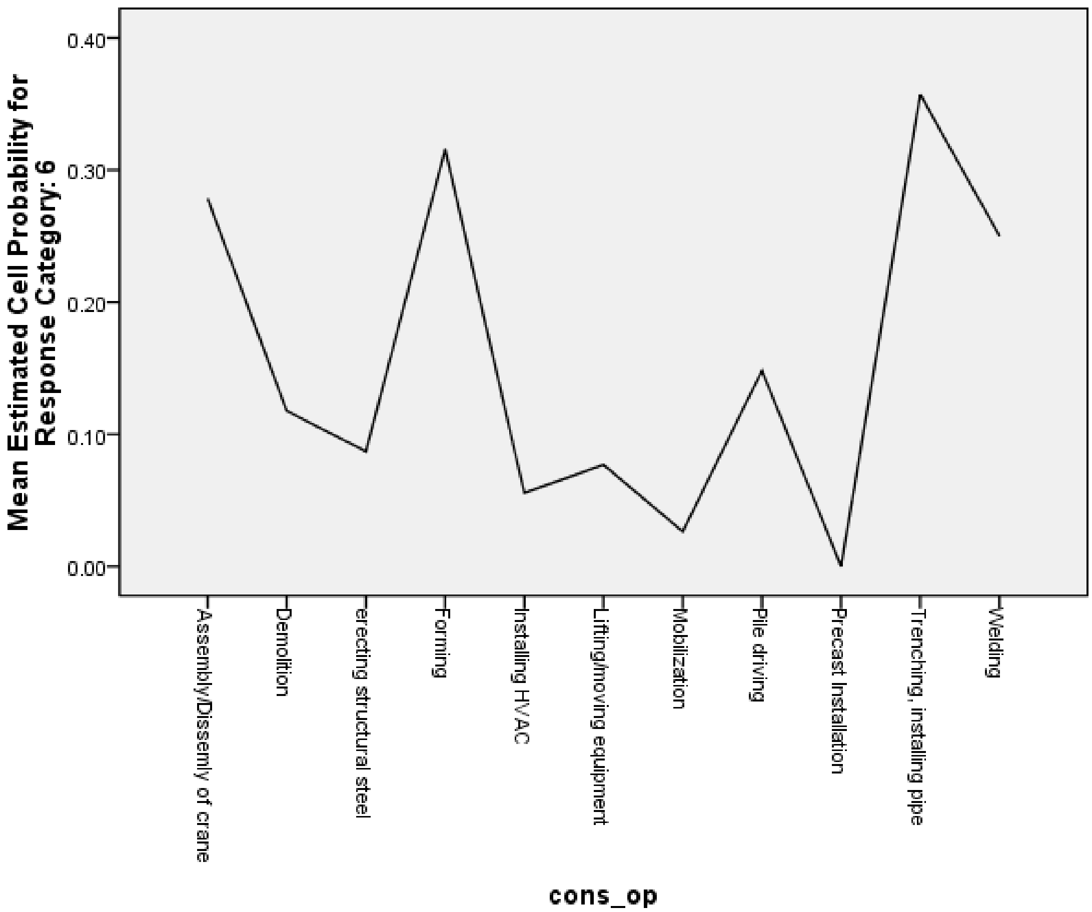

Figure 28 Significance of Construction Operations with respect to Failure of Boom

Figure 28 shows the estimated probabilities of failure of boom happening during various construction operations.

5.2.7 Electrocution

i. Degree of accident: Electrocution has no significant relationship with the degree of accidents (Fatal/non-fatal). However, examining the parameter estimates, the probability of electrocution is lesser with fatal accident and more with non-fatal.

ii. Fault Type: Electrocution is again not significantly dependent on the fault type. From the parameter estimates, the probability of Electrocution decreases with the technical fault.

iii. Construction Operation: Among the different construction types- types only installing HVAC including piping, ductwork and other equipment, mobilization. It should be noted that the parameter estimates and their respective significance is given taking the construction operation ‘Precast Installation’ as the reference category. All the construction operation types have negative parameter estimates showing that with each construction operation the probability of Electrocution decreases.

iv. Contributing Factors: None of the contributing factors were found to be significant to affect the value of probability for the occurrence of electrocution.

v. Occupation of the victim: As expected none of the victim’s occupation is significant and in fact they have negative estimate parameters which implies is not a important factor in electrocution.

vi. Load: As expected, load is also a redundant factor as far as ‘Electrocution’ of the cranes is concerned.

vii. Type of Crane: Mobile crawler crane, mobile truck crane and tower crane were significantly involved in Electrocution.

From all the above parameters the probability model equation is as shown below:

Logit Model

$\log\{\frac{1-\pi}{\pi}\} = 19.1 + [\text{fault}] + [\text{degree}] + [\text{Const}_{\text{Operation}}] + [\text{Contributing}_{\text{factors}}] +$

$[\text{Occupation}] + [\text{Load}] + [\text{Crane type}],$

where, table 32 provides parameter estimates for electrocution.

Table 32 Parameter estimates of Accident type (Electrocution)

Electrocution	Variable Value	Std. Error	p-value	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
Intercept	19.1	323.1	1.0		
[fatal=Non-fatality]	3.1	1.7	0.1	0.9	590.5
[fatal=Fatality]	0[b]	.	.	.	.
[fault=Technical]	-7.7	465.0	1.0	0.0	.[c]
[fault=Non-Technical]	0[b]	.	.	.	.
[cons_op=Assembly/disassembly of crane]	-43.9	871.6	1.0	0.0	.[c]
[cons_op=Erecting structural steel]	-29.7	957.7	1.0	0.0	.[c]
[cons_op=Installing HVAC including piping, ductwork and other equipment]	-1.0	2.4	0.037	0.0	38.3
[cons_op=Lifting/moving equipment and materials]	-19.2	323.1	1.0	0.0	4.4
[cons_op=Mobilization]	0.6	1.8	.04	0.1	59.8
[cons_op=Pile Driving]	-2.0	2.2	0.4	0.0	9.6
[cons_op=Precast installation]	0[b]	.	.	.	.
[cont_fact=Accelerated movement]	-18.4	1569.6	1.0	0.0	.[c]
[cont_fact=Boom Buckling]	-24.9	1319.1	1.0	0.0	.[c]
[cont_fact=Erecting structural steel]	13.0	465.0	1.0	0.0	.[c]
[cont_fact=Equipment Damage]	-27.3	1125.0	1.0	0.0	.[c]
[cont_fact=improper Communication]	-31.6	992.4	1.0	0.0	.[c]

Table 32 Continued

Electrocution	Variable Value	Std. Error	p-value	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
[cont_fact=Improper disassembly—pin removal]	26.0	1869.8	1.0	0.0	.[c]
[cont_fact=improper operation]	-1.9	1.7	0.3	0.0	4.4
[cont_fact=Inattention]	0[b]	.	.	.	.
[occup=Crane operator]	-6.3	3.6	0.1	0.0	2.0
[occup=Iron Worker]	27.9	0.0	.	15.2	15.2
[occup=Labor]	-1.8	2.7	0.5	0.0	34.6
[occup=Other]	-2.6	2.6	0.3	0.0	12.4
[occup=Technician]	0[b]	.	.	.	.
[load=Non-Loaded]	-18.2	323.1	1.0	0.0	1.2
[load=Loaded]	0[b]	.	.	.	.
[crane_type=Bridge Crane]	-13.0	1760.4	1.0	0.0	.[c]
[crane_type=Gantry Crane]	-3.2	2.2	0.1	0.0	2.9
[crane_type=Jib Crane]	-7.7	1411.5	1.0	0.0	.[c]
[crane_type=Mobile Crawler Crane]	43.2	846.7	0.02	00.0	.[c]
[crane_type=Mobile Truck Crane]	1.0	1.7	0.03	0.1	76.2
[crane_type=Tower Crane]	0[b]	.	.	.	.

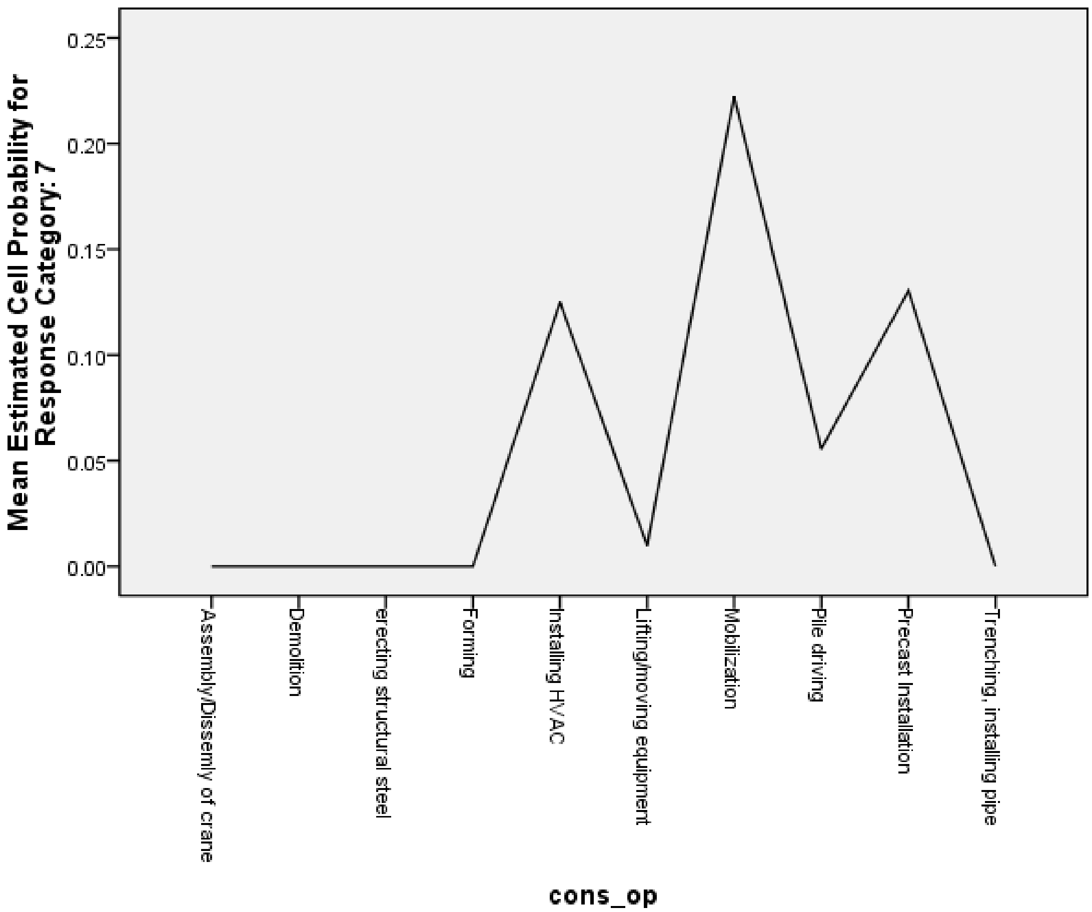

Figure 29 Significance of Construction Operations with respect to Failure of Electrocution

Figure 29 shows the estimated probabilities of failure of electrocution happening during various construction operations.

5.2.8 Fall

i. Degree of accident: The 'Fall' accident has no significant relationship with the degree of accidents (Fatal/non-fatal). However, examining the parameter estimates, the probability of the crane tip over accident is lesser with fatal accident and more with non-fatal.

ii. Fault Type: The accident type is again not significantly dependent on the fault type. From the parameter estimates, the probability of the ‘Fall’ accident increases if the fault is manual.

iii. Construction Operation: Although none of the construction operations have distinct significant relationship but the thing to be noted is that ‘Fall’ type accident does not happen with in every construction operation and the probability increases if the construction operation is ‘Assembly/disassembly of crane, demolition, erecting structural steel, installing HVAC, precast installation. It should be noted that the parameter estimates and their respective significance is given taking the construction operation ‘Trenching and installing pipe’ as the reference category. The maximum increase is shown by construction operation type -2 which is ‘Demolition’.

iv. Contributing Factors: Among the different contributing factors- types ‘Accelerated movement, Boom Buckling, Improper assembly, improper disassembly-pin removal, Overloading, and pin removal have a significant effect on the probability of the crane type accident. Interestingly, all these contributing factors have a negative parameter showing that the probability of this accident type actually decreases with these contributing factors. Inversely, that would mean that the probability of other accident types other than ‘Fall’ will increase because of these contributing factors.

v. Occupation of the victim: Interestingly, all the occupations are highly significant except ‘Iron Worker’. The parameter estimates show that the probability of occurrence of accident type ‘Fall’ is very high.

vi. Load: Surprisingly, Unloaded is an important factor as far as ‘Fall’ accident type is concerned. The parameter estimates show that the operation where crane is not loaded the probability of accident ‘Fall’ is more.

vii. Type of Crane: Only tower crane and jib crane have some significant relationship with accident type ‘fall’. This is expected but the parameter estimates show that mobile crawler crane and bridge crane also increase the probability of accident type ‘Fall’

From all the above parameters the probability model equation is as shown below:

Logit Model

$$\log\{\frac{1-\pi}{\pi}\} =$$

$$-23.154 + [\text{fault}] + [\text{degree}] + [\text{Const}_{\text{Operation}}] + [\text{Contributing}_{\text{factors}}] +$$

$$[\text{Occupation}] + [\text{Load}] + [\text{Crane type}]$$

where, table 33 provides parameter estimates for fall.

Table 33 Parameter Estimates for Accident type (Fall)

Fall	Variable's Value	Std. Error	p-value	95% Confidence Interval for Exp(B) Lower Bound	Upper Bound
Intercept	-23.154	1.994	.000		
[fatal=Non-fatality]	.446	.454	.326	.641	3.805
[fatal=Fatality]	0b	.	.	.	.
[fault=Technical]	-.301	.862	.727	.137	4.008
[fault=Manual]	0b	.	.	.	.
[cons_op=Assembly/disassembly of crane]	.499	1.304	.702	.128	21.213
[cons_op=Demolition]	.918	1.538	.551	.123	50.970
[cons_op=Erecting structural steel]	.437	1.343	.745	.111	21.514
[cons_op=Installing HVAC including piping, ductwork and other equipment]	1.240	1.408	.378	.219	54.620
[cons_op=Lifting/moving equipment and materials]	-1.838	1.404	.190	.010	2.493
[cons_op=Mobilization]	-2.655	1.723	.123	.002	2.059
[cons_op=Pile Driving]	-.795	1.497	.596	.024	8.492
[cons_op=Precast installation]	.236	1.374	.863	.086	18.716
[cons_op=Trenching, installing pipe]	0b	.	.	.	.
[cont_fact=Accelerated movement]	-16.689	4494.507	.997	.000	.c
[cont_fact=Boom Buckling]	-17.991	4240.616	.997	.000	.c
[cont_fact=Erecting structural steel]	.494	1.359	.716	.114	23.512
[cont_fact=Equipment Damage]	.664	1.294	.608	.154	24.527
[cont_fact=Improper Assembly]	-1.702	1.558	.275	.009	3.864
[cont_fact=improper Communication]	-1.019	1.450	.482	.021	6.183
[cont_fact=Improper disassembly—pin removal]	-2.906	1.489	.051	.003	1.013
[cont_fact=improper operation]	.871	.974	.371	.354	16.129
[cont_fact=Inattention]	.502	1.047	.631	.212	12.864
[cont_fact=Outrigger failure]	-.950	1.295	.463	.031	4.896
[cont_fact=Overloading]	-17.540	6995.380	.998	.000	.c

Table 33 Continued

Fall	Variable's Value	Std. Error	p-value	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
[cont_fact=Side pull]	-17.190	4055.617	.997	.000	.c
[cont_fact=Two Blocking"]	.257	1.186	.828	.126	13.230
[cont_fact=Wind]	0b	.	.	.	.
[occup=Crane operator]	18.539	.752	.000	2.577E+07	4.916E+08
[occup=Engineer]	17.532	.934	.000	612.248	2.567E+08
[occup=Iron Worker]	1.403	6826.037	1.000	.000	.c
[occup=Labor]	18.564	.724	.000	2.197E+02	4.772E+08
[occup=Other]	18.714	.756	.000	3.001E+02	5.904E+08
[occup=Technician]	18.756	.000	.	1.399E+08	1.399E+08
[occup=Welders]	0b	.	.	.	.
[load=Non-Loaded]	2.954	.999	.003	2.709	135.811
[load=Loaded]	0b	.	.	.	.
[crane_type=Bridge Crane]	.097	1.415	.945	.069	17.656
[crane_type=Gantry Crane]	-17.549	2863.539	.995	.000	.c
[crane_type=Jib Crane]	3.081	.949	.001	3.389	140.032
[crane_type=Mobile Crawler Crane]	.792	.614	.197	.663	7.351
[crane_type=Mobile Truck Crane]	-.484	.526	.358	.220	1.729
[crane_type=Tower Crane]	0b	.	.	.	.

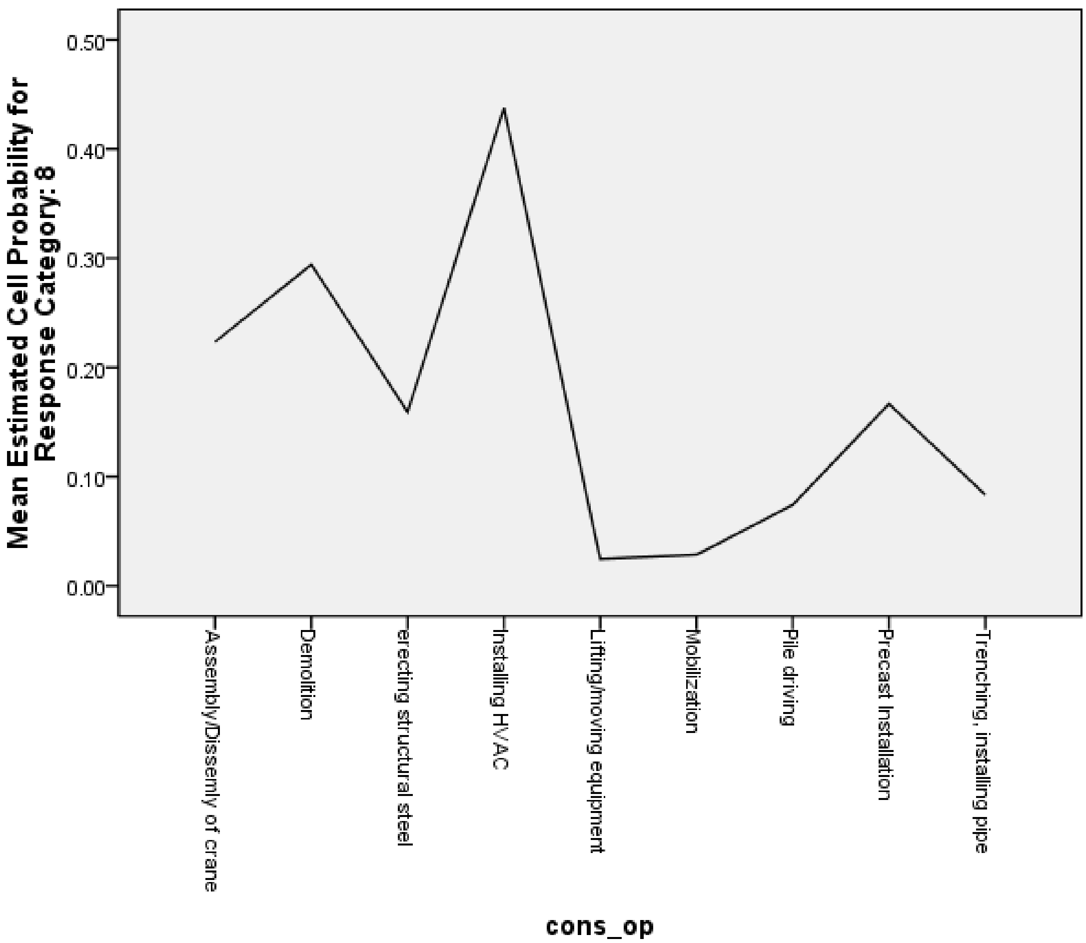

Figure 30 Significance of Construction Operations with respect to Fall

Figure 30 shows the estimated probabilities of fall happening during various construction operations.

6. CONCLUSIONS

6.1 General Conclusions

This thesis has provided a correlation between the crane accident types and the various factors involved during construction operations. Research also provides framework for advanced analysis which might include weather data such as wind, number of people in the working radius etc. The importance of the research can be derived from the Section 2 literature review of this thesis which clearly shows the lack of qualitative research for crane accidents in the construction industry and the desired need for the same. Literature review also revealed that there is no application of mathematical models in the construction industry for the cranes as far as safety is concerned. There have been few recommendations to use fuzzy logic for the selection of cranes but that only includes a mutually exclusive event and other safety variables are ignored.

Data was collected from OSHA online database where total of 670 accident reports were retrieved for years 2000 to 2006. Data collection shows that the frequency of crane accidents increased from 2000 to 2004 but the numbers have gone down since then till 2006. Contrary to the literature review which only deals with fatalities this research has analyzed both fatal as well as non-fatal accidents, henceforth the results are different. The primary variables which are accident types have been divided into 8 types namely, Crane tip over, Crushed during assembly/disassembly, Struck by load, Struck by crane parts, failure of cable, failure of boom, electrocution and fall. All these categories were derived from the analyses of 670 crane accidents inspections provided by OSHA. These categories also complied with the keywords used by OSHA to identify crane accident types. Similarly all the other variables such as contributing factors, crane types, victim's occupation etc were derived from the accident inspections.

Descriptive analysis shows that 'Struck by load' and 'Crane tip over' are the most prominent crane accidents that happen on construction sites, closely followed by Electrocution, Fall and struck by crane parts. Failure of cable, failure of boom and crushed during assembly/disassembly were least in numbers. It must also be noted that most of these crane accident types were found to be due to manual faults and similar effect can be seen on probability models. But the effect of fault type varies with different variables.

Descriptive analysis on the organs was performed so that the most affected organ can be provided more protection or extra cautionary measures can be applied. 'Head' was the most affected body part and it was closely matched by chest. It is to be notes that these organs were the main reason of fatality as well.

These injuries and crane accidents were caused by some contributing factors to these accidents. 19 types of contributing factors were found namely, Accelerated movement, boom buckling, Cable Snap, Equipment damage, Improper assembly, Improper Communication, Improper disassembly-pin removal, improper operation, inattention, intentional turntable, load dropped, outrigger failure, overloading, side pull, struck by vessel, two blocking and Wind. Improper operation and inattention were the main contributing factors, while all other contributing factors have similar frequencies.

All these contributing factors are found to be directly proportional to the construction operation. Lifting/moving equipment and materials, Assembly/disassembly of crane, demolition, erecting structural steel, forming, Installing HVAC & piping, mobilization, pile driving, Pouring Concrete, Precast installation, Trenching-installing pipe and welding were few construction operations were identified. Quantitatively Lifting/moving equipment and materials and Assembly/disassembly of crane have biggest percentages in crane accidents.

As far as victim's occupation is concerned, surprisingly it was labor which has been affected the most crane operators also form the major percentage of crane accident causalities. Engineers, technician and truck drivers have also been reported either injured or killed during crane accidents.

Descriptive analysis gave the relationship of one particular variable in a mutually exclusive manner but Logit modeling gave the correlation between all the variables. Model fitting information shows that the models are best fit and the pass the goodness test of fit. Log likelihood tests have analyzed the significance of a particular variable in a single model which has been discussed in Section 5.2.

Some interesting and surprising results were visualized through the probability models which are as follow-:

i) Contrary to expectations failure of cable and failure of boom accidents have difference with respect to significant variables. While technical fault, crane type(mobile crawler crane & gantry crane) and contributing factors(Erecting structural steel) were significant in failure of cable accidents; the only significant factor for failure of boom is 'Tower Crane'.

ii) Manual fault was more significant in accident types 'Struck by load' and 'Failure of cable'.

iii) Another interesting fact that has been derived from research is that construction operation is a significant factor for all construction types except 'Struck by load' and 'Electrocution'.

iv) It was found that instead of officials who regularly work near or with cranes has lesser probability of getting killed in a crane accident than the common labor force, especially when it comes to crushed during assembly/disassembly and failure of crane parts.

v) Load had been crucial factor for accident type 'failure of boom' but the probability model shows that most of the time for all other accident types load or overload has not been the primary responsible of crane accidents.

vi) Generally mobile crawler crane, mobile truck crane and tower crane were significant but their significant varies with different construction operations and accident types.

vii) Research shows that there is no significant difference between fatal and non-fatal accidents for all the accident types or proximal causes. Therefore ignoring non-fatal accidents is not appropriate.

viii) Although the probability of accident would vary from different conditions, but with 95% confidence it can be said that electrocution, crane tip over and crushed during assembly/disassembly have more probability of occurrence than other accident types.

6.2 Limitations

Unforeseen conditions can always be seen on construction site, which have never happened before. Therefore, there is always scope of improvement in the accident analysis which will further influence the accident probability. New construction techniques and methods can result in never seen accident type, contributing factor etc. There is always a chance of using the new crane type; henceforth the probability models will always have the scope of adding more variables and the latest database of crane accidents is the best source available. Therefore, these models are limited to time span till technological and methodical changes take place and it is always recommended to inculcate the latest data available.

6.3 Future Recommendations

Logit models can be a great simulation tool for safety mangers to assess different site conditions therefore first and foremost recommendation would be to apply these models in a user friendly software which allows even a mathematics novice to understand the probabilities of occurrence of crane accidents. Currently the variables have been entirely selected on the basis of OSHA inspections but other variability’s such as people in working zone while the crane was operating and some other variables which safety mangers might want to recommend.

The models will change as the data changes hence a database is required which identifies all the variables that affect the probability of the occurrence of a crane accident.

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VITA

Name:	Amrit Anoop Singh Bains
Address:	Department of Construction Science Texas A&M University 3137 TAMU, Langford Building A College Station, Texas 77843-3137
Email Address:	amritanoop@tamu.edu
Education:	B. Arch., B. Bldg. Sc., Panjab University Chandigarh, India, 2008 M.S., Construction Management Texas A&M University, College Station, TX, 2010